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LAKEVIEW TGS ACOUSTIC SOUNDING STUDY, JULY-DECEMBER, 1981

Report No 84-167-K

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ABSTRACT

This report summarizes and interprets acoustic sounding data collected in the vicinity of Lakeview TGS from July 1 to December 31, 1981. A summary of sounder performance is given and a comparison with minisonde data is done. The inversions determined from acoustic sounder patterns are described and their frequencies of occurrence are tabulated. The existence of "typical" sounder signatures associated with pollution episodes is postulated and supported with data. The data demonstrate that the sounders measure inversion heights reliably. It is concluded that acoustic sounders are worthwhile additions to on-site meteorological monitoring systems for many purposes and that the data provide useful information for decisions regarding intermittent emission controls at stations such as Lakeview TGS.

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To Mr. F.J. Kee
Director of Research

LAKEVIEW TGS ACOUSTIC SOUNDING STUDY
JULY-DECEMBER, 1981

1.0 INTRODUCTION

The structure of the lower atmosphere plays an important role in the transport and diffusion of air pollutants. For example, a capping inversion at the top of the well-mixed layer poses a barrier to air mixing and limits the height to which pollutants are transported. The height of this mixed layer, of course, is not constant with time, but depends on the strength of the surface-generated mixing, caused primarily by the effects of thermal convection. As well, thermal fluctuations occur at or near the top of the well-mixed layer as turbulent air below interacts with the stable layer aloft.

These small-scale thermal fluctuations reflect sound signals and this has led to the development of acoustic sounding as a remote sensing technique for probing the lower atmosphere. Acoustic sounders are increasingly being used in atmospheric science for the continuous remote sampling of a variety of parameters. Unfortunately, most applications of acoustic sounders to date have been of a research nature, no doubt because acoustic sounders have required a large commitment of staff, automated data handling equipment and auxiliary support measurements.

Ontario Hydro requires information on the structure of the lower atmosphere for many applications. Such information is important whenever dispersion models are to be applied for design and licensing of new facilities, or for operation of existing ones, both thermal and nuclear. In the case of thermal facilities, for instance, this type of information is useful in the operation of intermittent emission control programs, whereas in the case of nuclear facilities, the information may be used for contingency planning.

This report deals with the needs related to intermittent emission controls at thermal power plants. More specifically, this report describes a study carried out to (a) demonstrate that an array of monostatic acoustic sounders can be operated in a continuous monitoring mode and (b) develop the necessary maintenance and data interpretation skills to make future operational use of the technique a valid alternative.

The ability of the acoustic sounder array to monitor the lowest 1 km of the atmosphere is reported. Details of the experience we've gained operating the array are provided. As well, the acoustic sounder measurements are compared with minisonde data, and the frequency of occurrence of inversions, which are important in understanding dispersion in lakeshore environments, is presented. Finally, this report examines the relationship between acoustic sounder data and the ground-level SO_2 concentration in the Lakeview TGS area.

2.0 EXPERIMENTAL

Two monostatic and one monostatic/bistatic AeroVironment Model 300C acoustic sounders were deployed in the Lakeview TGS area from July 1 through December 31, 1981. In order to monitor the complexities of the lakeshore environment, one sounder was located close to the lakeshore and the other two farther inland. The location of the sites is given in Figure 1. Further details of the sites and their periods of operation are given in Table I.

The Lakeview TGS area was chosen for this survey for several reasons. The Lakeview Fall Episode Study (Edwards, 1982) was planned for part of the same period and it was felt that the sounder array would provide valuable data for that study. Exceedances of the SO_2 hourly air quality criterion are experienced at sampling station WO7, Figure 1, with relatively high frequency and the potential of acoustic sounders to provide data that may help explain such exceedances was of interest to Thermal Generation Division. Lakeview TGS is located close to an urban area (Metropolitan Toronto has a population of about 2.5 million); thus, the understanding of the impact of power plant emissions on air quality in this area needs to be well defined. Finally, Lakeview TGS's proximity to the Research Lab allowed us to make weekly visits to service and maintain the sounders at minimal cost.

An introduction to acoustic sounding and descriptions of the equipment and technique were presented in Ontario Hydro Research Division Reports 81-324-K and 82-79-K and will not be repeated here. Instead, we will limit discussion in the next section to details of siting, data capture, sounder performance and chart interpretation.

3.0 OPERATIONAL EXPERIENCE

3.1 Siting

The siting of acoustic sounders in urban environments presents special problems, due mainly to the sounder's amplified "listening" capabilities and the 100-watt sound pulse which is emitted every 18 seconds. While these observations are generally true, we found that siting a monostatic unit posed far fewer problems than siting a bistatic unit. The area needed for a monostatic unit is relatively small ($\sim$4 m^2) and the sound source is enclosed by a lead-impregnated, foam-lined shelter, which lessens the noise of the 100-watt, 1 600 Hz

TABLE I

ACOUSTIC SOUNDER SITES

Unit No	Site Name	Direction from Lakeview TGS	Distance (km) from Lakeview TGS	UTM Coordinates	Type of Sounder	Installed	Removed
1.	Evans Ave (MOE Met Tower)	30°	5.8	4830200 mN 619350 mE	Monostatic	Apr 11/81	Dec 31/81
2.	Gateway PO (Eglinton Ave & Dixie Rd)	325°	8.9	4832300 mN 611950 mE	Monostatic	Jun 11/81	Aug 19/81
2.	Domtar (Mavis Rd & Dundas St W - near WO7 SO_2 monitor)	272°	6.5	4825150 mN 610500 mE	Monostatic	Aug 20/81	Dec 31/81
3.	Claireville TS (Hwy 27 & Steeles)	350°	22.0	4845600 mN 612700 mE	Monostatic/ Bistatic	Jun 23/81	Aug 20/81
3.	Hwy 10 (Britannia Rd W & Hwy 10)	300°	11.4	4830800 mN 607100 mE	Monostatic/ Bistatic	Aug 21/81	Dec 31/81

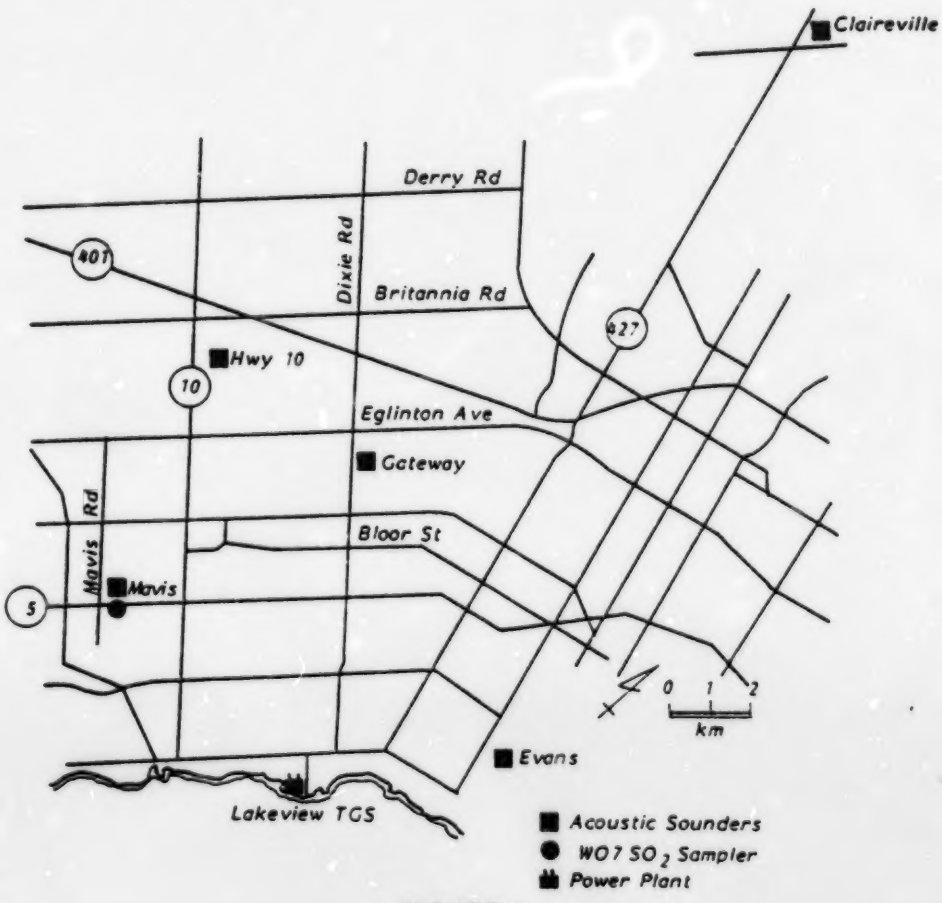


FIGURE 1

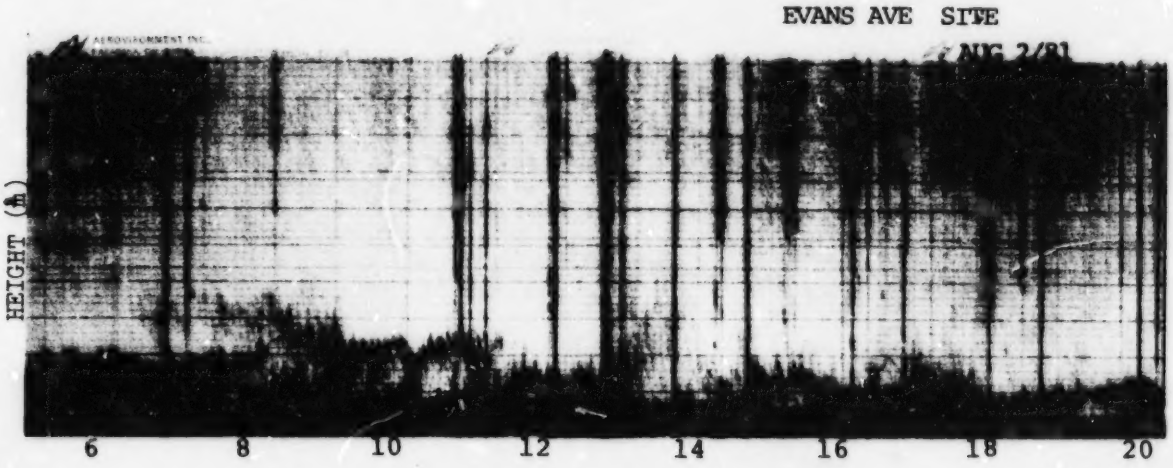
LAKEVIEW ACOUSTIC SOUNDER SITES

sound pulse in the horizontal direction. The bistatic unit requires a large baseline (∿150 m) between the monostatic unit and the bistatic transmitting dish. Additionally, the bistatic transmitter dish is not enclosed in sound absorbing material although it still transmits the standard 100-watt signals.

In spite of these difficulties, sites were found around Lakeview TGS and the quality of the data collected appears good, except for some background noise. Figure 2 shows an example of data recorded at the Evans Ave site, which is located 200 m south of the QEW highway. The gray shades represent atmospheric structuring due to temperature inhomogeneities. The dark vertical lines reaching the top of the record are the direct result of surface and air traffic.

FIGURE 2

DATA QUALITY NEAR A HIGH AMBIENT NOISE SOURCE



3.2 Data Capture

Table II shows the data capture rate in days per month per site. It can be seen that the data capture rate was very high for these sounders, especially the Claireville bistatic sounder, for which the rate was 100%. As described in Lemyk (1982a) the quality of these acoustic sounder data was very good.

3.3 Sounder Performance

During the six-month study period, only one electronic breakdown occurred, resulting in three days of lost data. The problem appears

TABLE II

SUMMARY OF ACOUSTIC SOUNDER DATA RECOVERY
LAKEVIEW TGS, JULY-DECEMBER, 1981

Month	Unit*1			Unit*2			Unit*3+		
	Sampling Days	Days with Data	% Data Recovery	Sampling Days	Days with Data	% Data Recovery	Sampling Days	Days with Data	% Data Recovery
July	31	19	61	31	31	100	31(31)	29(31)	94(100)
August	31	31	100	30	21	70	17(17)	17(17)	100(100)
September	24	22	92	30	30	100	30(22)	23(8)	77(36)
October	31	25	81	31	29	94	31	28	90
November	30	29	97	30	30	100	30	30	100
December	31	31	100	31	31	100	31	31	100
TOTAL	178	157	88	183	172	94	170(70)	158(56)	93(80)

*See Figure 1 and Table I for siting details

+Values in brackets refer to bistatic component of Unit 3

to have been associated with the integrated circuits in the writing system, where an electrical current is transmitted through the stylus and etches a vertical trace on the chart paper. The etching process results in the formation of carbon deposits inside the recorder electronics which can result in electronic failure. The replacements were purchased off-the-shelf. Preventative maintenance, such as vacuuming off the carbon deposit, has proven somewhat effective. The carbon build-up can also be minimized by leaving the recorder door open during operation, thus allowing the fine carbon particles to disperse. A second major problem involved the mechanics of the sounder chart take-up system. This system consists of three components. The first of these, the take-up motor drive, has proven reliable. The second, the rubber "O" ring connecting the motor drive to the chart take-up roller, occasionally failed to advance the chart at the proper rate due to slippage. Carbon deposits were found inside the roller. This would no doubt eventually lead to seizures. Vacuuming the roller to remove carbon deposits has been found insufficient. Instead, the roller assembly must be removed and thoroughly cleaned. The third component of the take-up system, the tensioner, is difficult to adjust. The manual states how adjustments can be made, but in reality the adjustments have been found to be a matter of trial and error, a laborious and time-consuming task in the field.

3.4 Data Interpretation

Previous reports, especially Lemyk (1982b), have presented details of the acoustic sounder data interpretation techniques. For completeness, a summary of the principles of data interpretation is given in Appendix B. For this report, the analysis has been extended to include estimates of atmospheric stability with elevation. As stated in Appendix B, stable layers appear as dense horizontal records, whereas unstable layers are generally seen as "spiky" and less dense, horizontally. Varying shades of grays to black are produced as a direct result of atmospheric temperature inhomogeneities. Since the strength of the return signal is directly proportional to the vertical temperature gradient a method of estimating stability strengths is proposed in Table III.

TABLE III

STABILITY CLASSIFICATION SCHEME
(Stable and Unstable Cases)

Group	Stability Strength	Intensity of Facsimile Shading
1	Very weak to weak (VW-W)	Light gray
2	Moderate (M)	Gray to dark gray
3	Strong (S)	Black

The technique devised has shown promising results in categorizing strong, moderate and weak stable to unstable layers, especially in conjunction with low ambient noise levels. Section 4.0 will demonstrate this method more fully.

The heights of distinct atmospheric layers abstracted from the acoustic sounder charts have been summarized elsewhere (Lemyk, 1982a). The heights given in that report are those to the top of a surface-based layer or the base of the first elevated layer "seen" by the sounders. These data are discussed in some detail in later sections of this report.

3.5 Summary

Based on the experience gained during the study, the following guidelines have been compiled for site selection:

1. Because of the transmitted sound pulse of 100 watts at 1 600 Hz, the sounder (especially the bistatic unit) should be situated in a relatively isolated area.

2. When onshore flows are of primary interest, as here, sites should be located upwind of potentially high ambient noise levels such as high traffic areas.

3. A clear passage (45°) measured from the top of the sounder enclosure to the nearest obstruction must be maintained. This will reduce passive noise.

4. Reasonable security, for the safety and protection of instrumentation, should be considered.

5. Access to power is a requirement.

The acoustic sounders have generally been found to be a reliable field instrument. Very few problems were encountered in the six months of continuous operation. On completion of the Lakeview TGS survey, the instruments were checked and still found to be within the prescribed operating range set by AeroVironment, the manufacturer.

4.0 COMPARISON OF ACOUSTIC SOUNDER AND MINISONDE RECORDS

Skill in interpreting acoustic sounder charts and confidence in the results of such interpretations can be greatly improved by referring to comparative data obtained by more familiar and proven techniques. It was for these reasons that a comparison between acoustic sounder charts and minisonde flight data was performed.

The minisonde data used for the intercomparison were taken either as part of the Lakeview Fall Episode Study (LFES) or as part of the Lakeview Extraordinary Control Program, operated by Power System and Operations Division. Details of these minisonde data can be be found in Tam (1982) and Fraser (1982), respectively.

This report only focusses on days with onshore winds. Unless specified otherwise, onshore winds were taken as those between 040° (NE) and 240° (SW), as measured at the Malton Weather Station. Nineteen cases were selected in seven days in which minisonde measurements had been made at or near one of the sounder sites.

A comparison of the elevation, thickness and intensity of convective and stable layers measured by the acoustic sounder and the minisonde techniques is given in Table IV. (Details of the descriptions used in the table are illustrated in Appendix A, Figures A1 to A7). It can be seen that acoustic sounder records are consistent with minisonde temperature profiles. Where the minisonde profiles show an elevated inversion, the sounder records show darker facsimile signals at or near the same elevation. This good agreement is also shown in Figure 3 where the top and bottom layers determined by both techniques are plotted. Regression equations and correlation coefficients (r) are also shown in Figure 3.

In summary, the layering shown on the sounder chart correlates well in height, stability, strength and thickness with the layers measured by minisonde. It appears that a technique could be developed to estimate temperature profiles from surface temperature measurements and acoustic sounder records. This development would, of course, require more intensive comparative data. Such a technique could aid in building up climatological statistics on mixing heights or could be useful in making short period forecasts of pollutant dispersion.

5.0 INVERSION HEIGHT MONITORING

The Thermal Internal Boundary Layer (TIBL) is the predominant mechanism causing high short-term SO_2 ground-level concentrations through fumigation from tall stack emissions (Lui, 1979; Portelli, 1982; Misra, 1982). TIBL development occurs when cool stable marine air moves inland during daytime hours. Strong insolation leads to warming at the surface, erosion of the lake-induced stability, ie, TIBL formation.

As shown in Figure 4, TIBL's occur frequently. A property of the TIBL's formed near Lakeview TGS, TIBL height as a function of distance from the shore, is examined in the next section.

TABLE IV

THE ELEVATION, THICKNESS AND INTENSITY OF DISTINCTIVE ATMOSPHERIC LAYERS AS DETERMINED BY THE MINISONDE AND ACOUSTIC SOUNDER TECHNIQUES

Case #	Date	Time (EST)	Minisonde		Acoustic Sounder	
			Inversion Height (m)	Visual Stability Strength	Inversion Height (m)	Visual Stability Strength
1	Sept 11/81	0712*	0-860	Moderate	0-800	Moderate
2		0826‡	180-340	Moderate	160-360	Moderate
			450-960	Weak to Moderate	380-940	Weak to moderate
3		1124	480-660	Strong	420-600	Strong
4		1315	200-450	Strong	300-460	Strong
5	Sept 14/81	0820	225-300	Strong	220-320	Strong
6	Oct 13/81	1030	360-460	Strong	360-560	Strong
7		1200	530-640	Strong	500-620	Strong
8		1400	300-500	Moderate to Strong	300-500	Strong
9		1500	300-400	Moderate to Strong	280-400	Strong
10	Oct 14/81	0900	160-280	Strong	140-280	Strong
11		1030	210-680	Moderate	200-600	Moderate to Strong
12		1230	160-220	Moderate	160-220	Moderate
13	Nov 4/81	0745	240-360	Weak to Moderate	180-320	Weak to Moderate
14		1100	380-520	Moderate	300-500	Moderate
15	Nov 5/81	0731	0-440	Moderate	0-320+	Moderate
16		0907	80-360	Moderate	100-300+	Moderate to Strong
17		1210	100-400	Moderate	120-420	Moderate to Strong
18	Dec 30/81	0855	150-300	Moderate	120-320	Moderate
19		1030	140-300	Strong	120-320	Strong

* - Multiple layers - no distinctive separation.
‡ - Multiple layers - fairly distinctive separation.
\+ - Data quality only fair. Sounder shows both surface and elevated inversion layers.

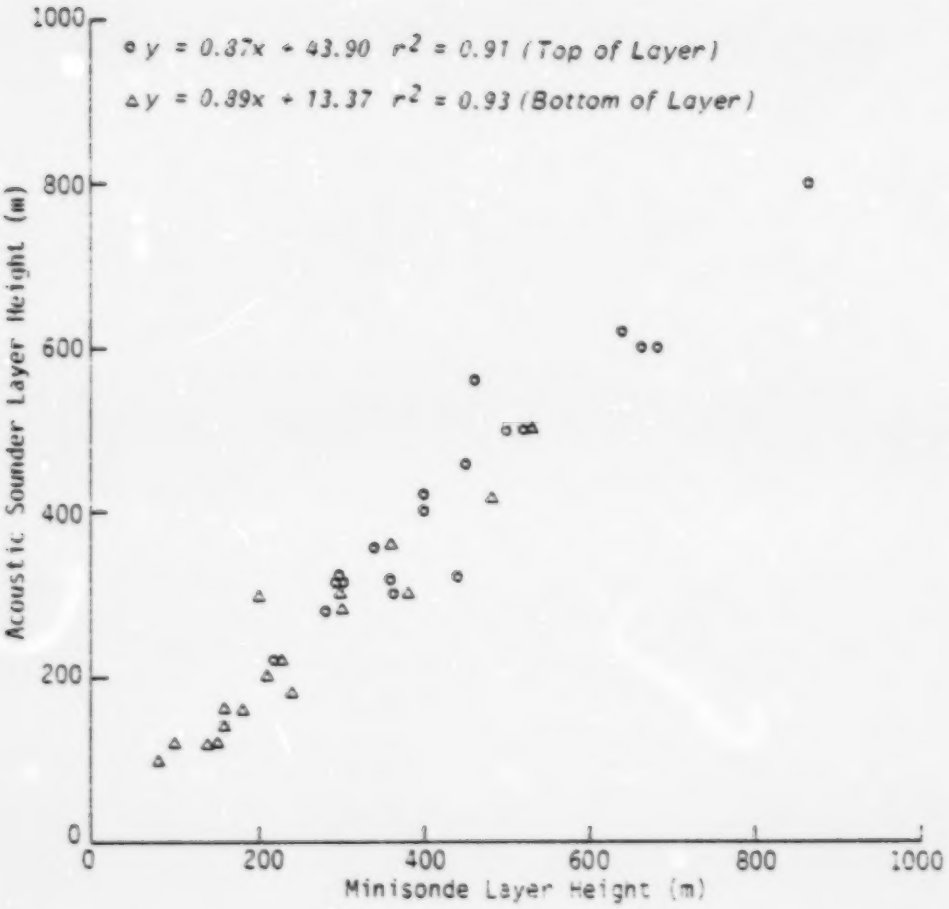


FIGURE 3

LOCATION OF THE TOP & BOTTOM OF DISTINCTIVE ATMOSPHERIC LAYERS AS DETERMINED BY MINISONDE AND ACOUSTIC SOUNDER TECHNIQUES

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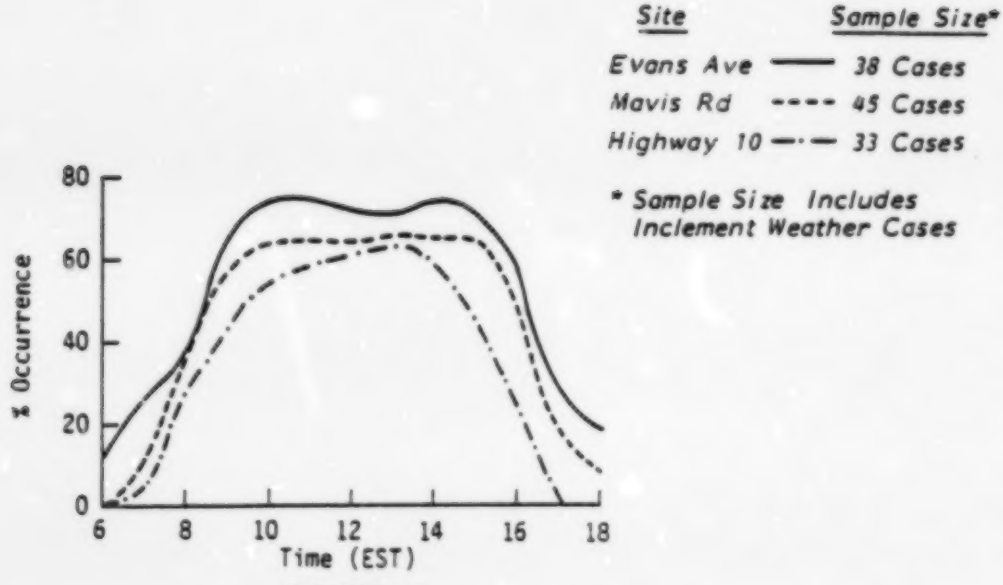

.FIGURE 4
% OCCURRENCE OF THERMAL INTERNAL BOUNDARY LAYER

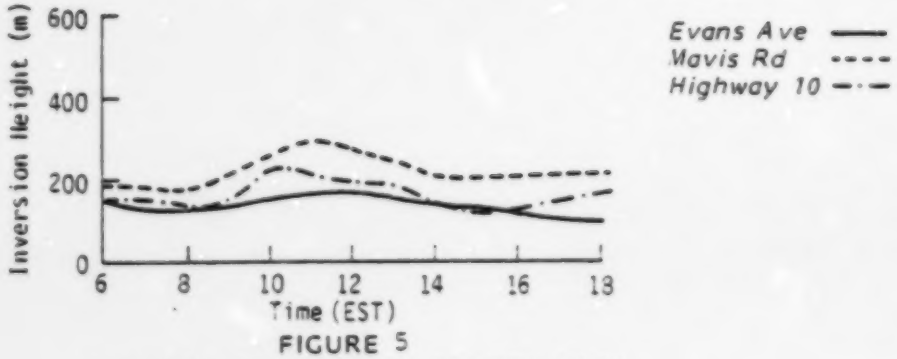

FIGURE 5
SUMMARY OF INVERSON GROWTH WITH DISTANCE INLAND - SEPT, OCT, NOV, DEC 1981

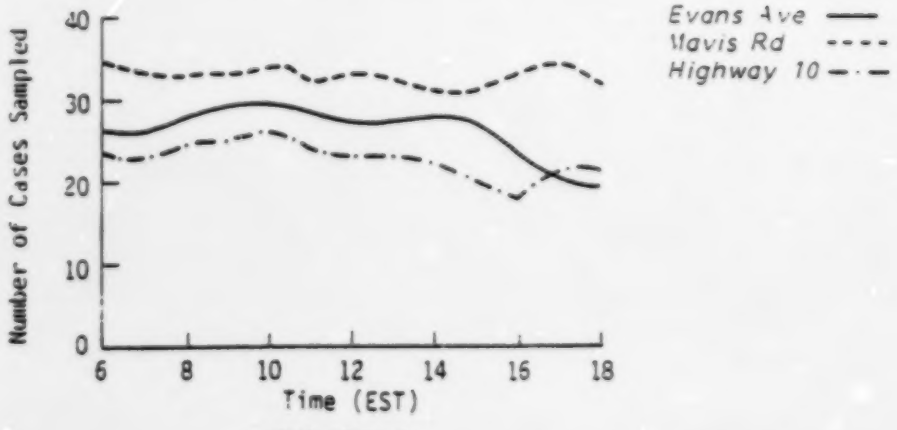

FIGURE 6
SUMMARY OF CASES SAMPLED

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5.1 Variation of Layer Height With Distance from the Shoreline

Several lakeshore studies (Lui, 1979; Portelli, 1982) have shown, on the basis of one or two cases each, that the development and growth of the TIBL with distance inland is roughly parabolic. We will begin our investigation of TIBL growth rate by looking at whether systematic differences exist in layer heights with distance inland.

A comparison of the height of the base of elevated inversions measured at three sites is shown in Figure 5. Because not all sounders showed the same layers at all times, Figure 6, showing the actual number of cases sampled is also included. The results show that inversion height grows more rapidly and higher at the inland sites than at the lakeshore site. Common among the sites are the relatively equal layer heights in the early morning (0600 EST) and the large increases of heights occurring in mid-morning (1000 EST), and peaking by ∿1100 EST.

One would expect the base of the stable layer to be higher at the Highway 10 site than at the Mavis Rd site since the former is farther inland. This is not borne out by the data, and the discrepancy may be related to the different topography of the two sites. The Mavis Rd site lies ∿0.7 km directly downwind of a subdivision of homes sheltered in a valley. These local features represent an increase in surface roughness. The Highway 10 site is located downwind of a cornfield, which stretches ∿1 km. Reduced surface roughness exists at this site.

However, another simple explanation should be pursued before the anomaly is attributed to differences in surface roughness. When the wind blows onshore from 040°, the fetch to the various sounder sites is quite different from the fetch when the wind blows from, say 180°. To really compare inversion heights with distance inland, the comparison should be done along the wind direction.

Of course, in addition to having different fetches, different wind directions also have different roughness lengths depending on building heights, etc. In an attempt to avoid some of these problems, a wind direction envelope of 070°-190° was chosen as representing onshore flows in which the effects of differences in fetch on the sounder data are small.

Figure 7 shows the height of the mixed layer for onshore winds from 070° to 190°, during the six study months. It can be seen that the maximum layer height occurs at ∿1100 EST, and the minimum at about 1600 EST. The layer height grows more rapidly and reaches a higher level at the inland sites (the Highway 10 site shows the lowest layer height). It can also be noted that the Mavis Rd site experienced higher convective plumes than the Highway 10 site. This is again thought to be the result of surface roughness due to topographical differences between the two sites.

Since this general summary has resulted in somewhat inconclusive results, two examples, shown in Figure 8(a) and (b), have been selected to show the growth of the mixed boundary layer in a slightly different way.

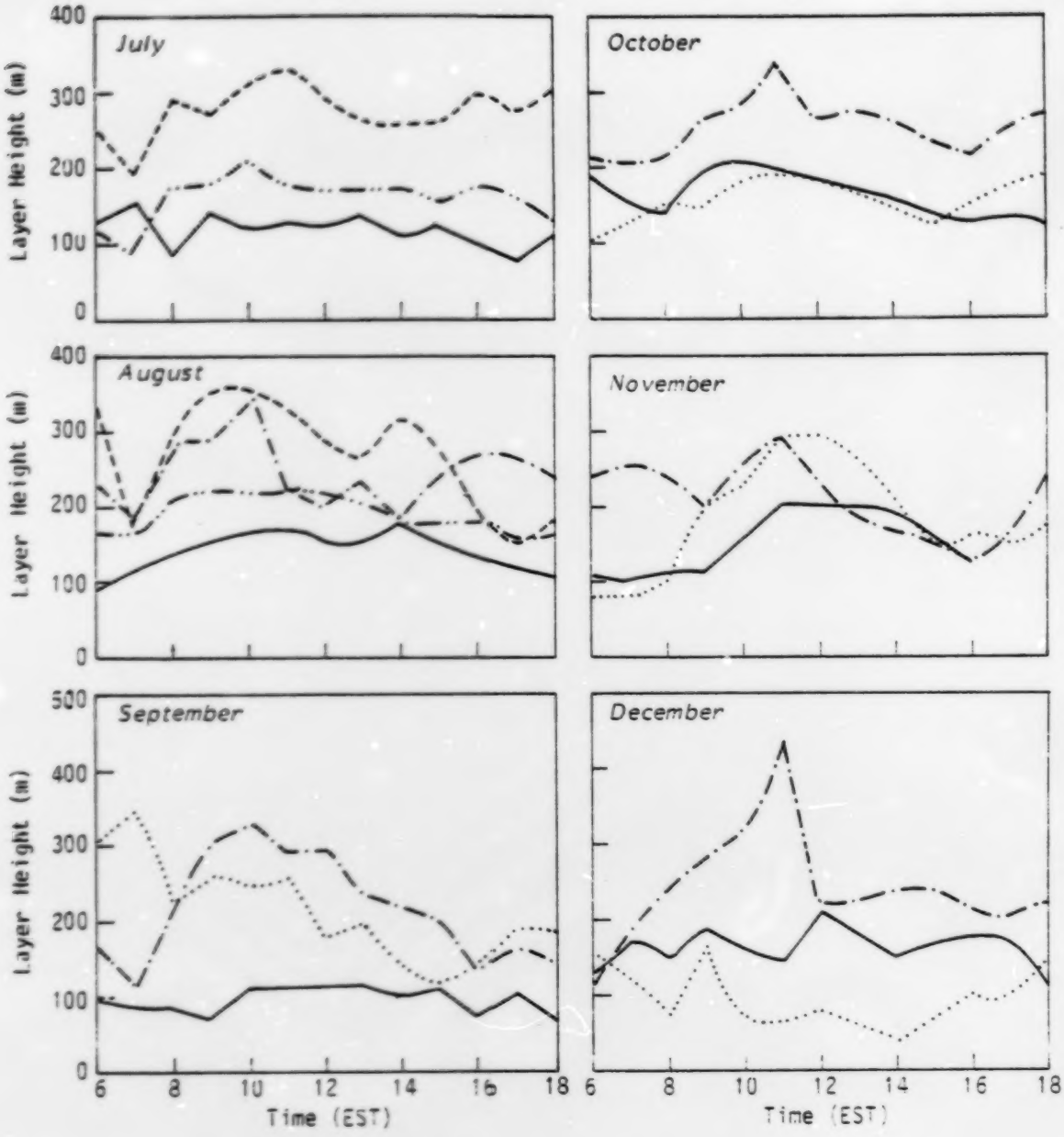

FIGURE 7

MIXED BOUNDARY LAYER HEIGHT FOR
ONSHORE WINDS FROM 070° TO 190°

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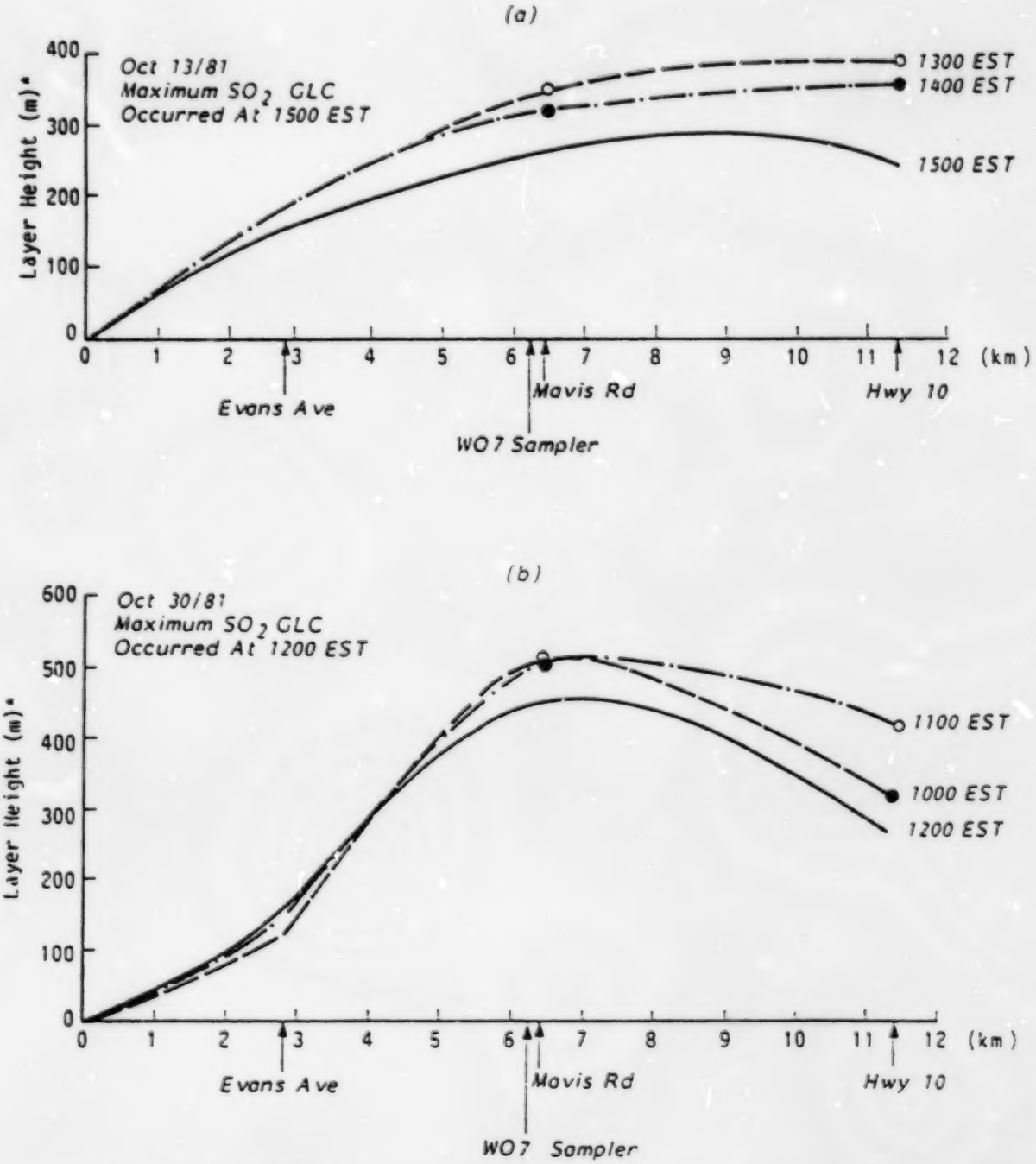

* Corrected for differences in site elevations.

FIGURE 8

BOUNDARY LAYER GROWTH WITH DISTANCE INLAND AND TIME

165259 RD

The example in Figure 8(a) shows the shape of the elevated stable layer base on October 13, 1981. The behaviour is close to what is believed to be common. The hours in which high ground-level SO_2 concentrations were measured are shown.

Figure 8(b) shows the shape of the elevated stable layer base at 1000, 1100 and 1200 EST, the period in which higher than normal ground-level SO_2 concentrations occurred on October 30, 1981. This is a case in which the inland height at the site farthest inland is lower than that measured at Mavis Rd, possibly for reasons already discussed.

During onshore winds, the Evans Ave site is usually under the influence of the stable marine air advected from the lake. Very few cases, where convection was strong enough to erode the stable marine air, were monitored at this site. However, farther inland, at the Mavis Rd site, convective mixing is quite strong as evidenced by the large increase in the layer heights. Acoustic sounders show that the TIBL is quite often sufficiently high at this point to intersect the elevated plume causing fumigation. This was in fact seen on both days.

5.2 Frequency Distribution of Layer Depths

Elevated stable layers have a strong influence on plume rise and ground-level concentrations of pollutants. Plumes emitted above such layers are effectively isolated from the ground, whereas plumes emitted beneath these layers will have their rise retarded. Lakeshore sites are known to have an inordinately high frequency of occurrence of elevated stable layers.

Given the ability of the sounders to detect stable layers, and the importance of such layers at a site such as Lakeview, an attempt was made to determine the frequency of occurrence of (a) surface stable and unstable layers, and (b) elevated stable layers. The analysis was limited to the daytime hours from 0600 to 1800 EST and for onshore winds. A qualitative estimate of stability strength was attempted (see Section 3.4). However, because of the few onshore cases, the analysis of stabilities was based on only two classifications, very weak to weak and moderate to strong. Figures 9 to 11 present the analysis for the Evans Ave, Mavis Rd and Highway 10 sites, respectively, for September 1 through December 31, 1981, when the sounders were not moved and data recovery was good.

Unstable, surface-based layers rarely occur overnight but are typically monitored during the daylight hours. A similar number of unstable cases was present at both the Evans Ave and Mavis Rd sites with the latter showing a more rapid growth rate, 0.23 m s^{-1} and 0.48 m s^{-1}, respectively. The averaged maximum growth for Evans Ave was 170 m at 1200 EST, whereas the maximum growth at the Mavis Rd site reached 240 m by 1000 EST. Results at Highway 10 are quite similar to those at Mavis Rd.

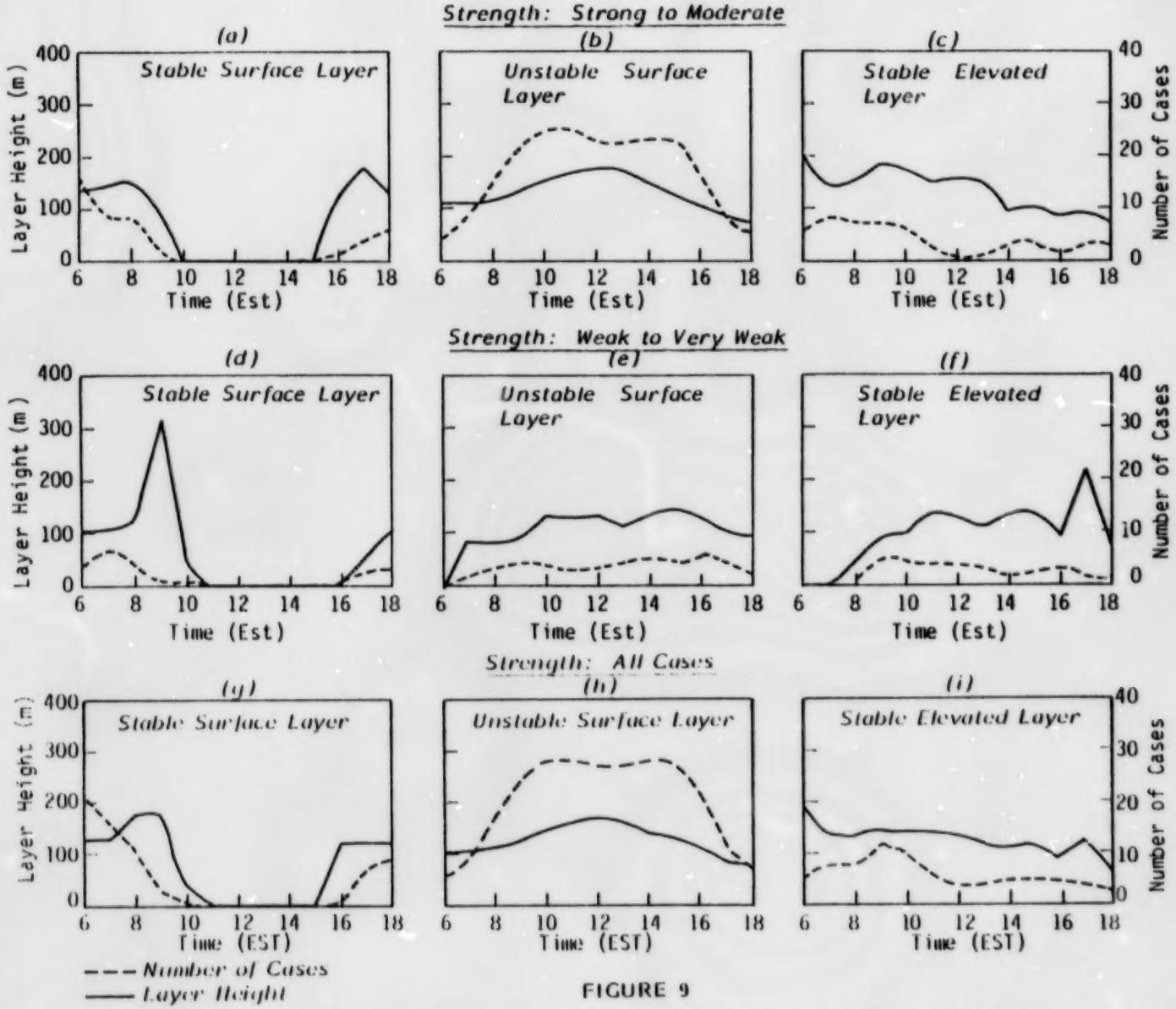

FIGURE 9

STABILITY STRENGTHS AND LAYER HEIGHT DURING DAYTIME HOURS
(EVANS AVE SITE)

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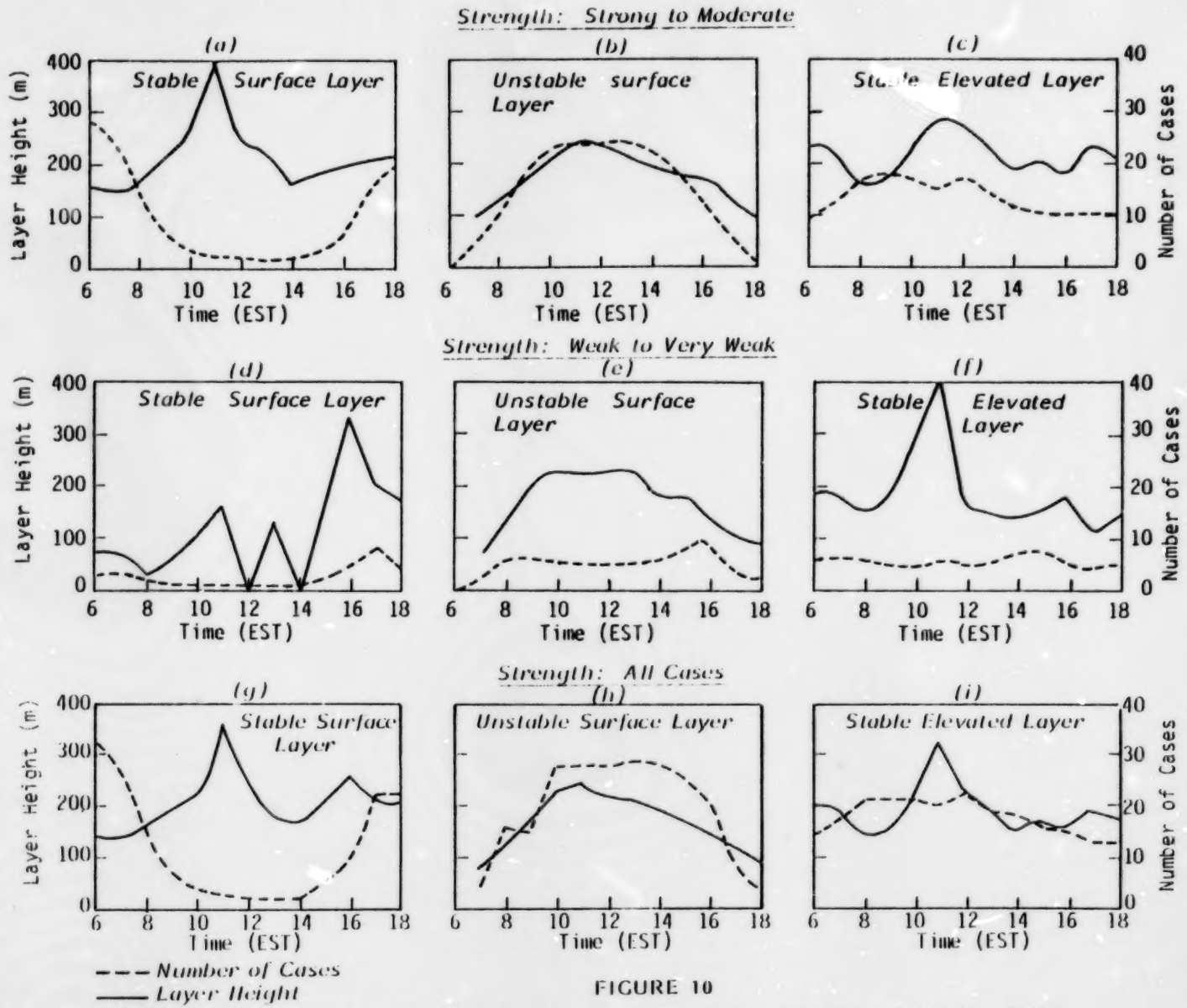

FIGURE 10

STABILITY STRENGTHS AND LAYER HEIGHTS DURING DAYTIME HOURS
(MAVIS RD SITE)

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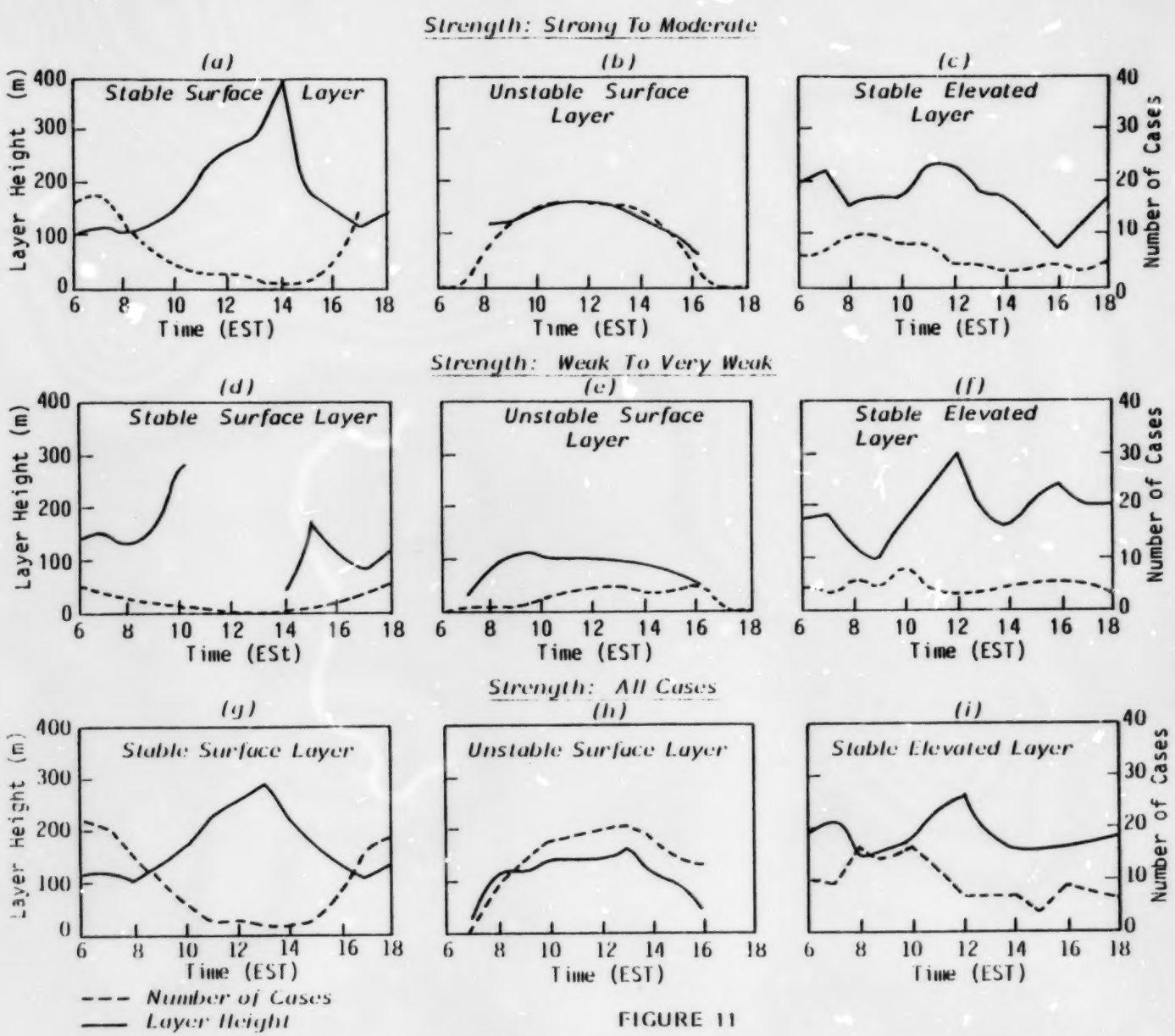

FIGURE 11

STABILITY STRENGTHS AND LAYER HEIGHTS DURING DAYTIME HOURS
(HWY 10 SITE)

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Although data on nocturnal surface-based inversions (NSBI) have not been included in this report, sounder records documenting the existence of these situations have been collected. These inversions are normally eroded from below by convective activity induced by solar heating. Typically very few cases remain after 1000 EST at the Evans Ave site, Figure 9(a).

It is difficult to know what level of certainty to give the values presented in Figures 9 to 11. The average layer depths indicated are lower than those measured on days when air pollution episodes have been studied intensively (Edwards, 1982). Of course, the fact that the data are largely for fall conditions may explain this somewhat. Also, perhaps the high ambient noise, at the Evans Ave site especially, may have resulted in the sounder missing the higher structure on some days. This point should be resolved by later studies at quieter sites.

Because of the relatively few cases in each category, little general information can be gleaned from this analysis. However, it still can be seen that unstable surface layers occur quite frequently during the daytime and the heights of the convective cells display the typical diurnal behaviour as discussed previously. Stable elevated layers, on the other hand, occur less frequently during the daytime. It appears that, given a longer sampling time at quieter sites, a more definitive frequency distribution could be developed based on sounder data.

The ability of the acoustic sounder to measure and record temperature inhomogeneities results in some kind of structure being present on the vast majority of onshore wind days. In fact, in the present six-month study period, the combined sites only recorded 221 hours, as shown in Table V in which the atmosphere was so uniformly neutral that no structure was perceived.

The highest frequency of occurrence of neutral cases was recorded between 0600-0800 and 1600-1800 EST, with a higher frequency in the latter period. A transition period, lasting <1 h, in which a changeover occurs from daytime convective heating to nighttime nocturnal cooling of the surface, takes place in the late afternoon. The atmosphere, of course, goes through a neutral phase in the process.

In summary, acoustic sounder data can be readily analyzed to give frequency distributions of the height and strength of distinctive atmospheric layers, according to the procedures developed here. The task of relating these heights and intensity to plume dispersion still remains. The following section attempts to do this by analyzing several specific episodes in which higher than average ground-level SO_2 concentrations occurred in the Lakeview TGS vicinity.

TABLE V

FREQUENCY OF OCCURRENCE (HOURS) OF
NEUTRAL STABILITY
LAKEVIEW AREA, 1981

Month	Site	Time - EST 0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800
July	Evans Ave	1	1	1										
	Claireville										1			
	Gateway													
Aug	Evans Ave	3	2	1	1					1	1	2	2	2
	Claireville	2	2	2	1	1	1	1	1	1	1			
Sept	Evans Ave											1	1	2
	Mavis									1	1			
	Hwy 10									1	1			
Oct	Evans Ave											3	3	3
	Mavis						1							
	Hwy 10				1	1	2	3	3	2	3	5	1	
Nov	Evans Ave	1	1	1	1	1	1	1	1	1	1	1	2	2
	Mavis													
	Hwy 10	1	1	1	1								1	1
Dec	Evans Ave	4	4	4	4	4	4	4	4	4	4	4	5	5
	Mavis													
	Hwy 10	5	5	6	6	6	6	6	6	6	7	6	6	6
Total Hourly Cases		17	16	16	15	13	15	15	15	17	20	22	21	21

Note: Cases where inclement weather, such as fog, rain or snow could constitute neutral stability are not included.

6.0 ACOUSTIC SOUNDER RECORDS DURING PERIODS OF HIGH GROUND-LEVEL SO_2 CONCENTRATIONS

For simplicity, this discussion is limited to days during July to December, 1981 when the maximum hourly average SO_2 concentrations recorded at the WO7 sampler exceeded 50 ppb. WO7 was chosen for this analysis because it is the sampler that most frequently indicates exceedances of the hourly SO_2 air quality criterion (250 ppb) in the Lakeview area. Moreover, wind directions during the cases selected for study were from the SE quadrant; hence, WO7 is likely to be the monitor closest to the location of the maximum ground-level concentration. A total of 13 cases were selected, see Table VI for details.

Note that no cases of high nighttime ground level SO_2 concentrations were reported. This is primarily due to a combination of low station load at night and the development of ground-based nocturnal stable layers. Therefore,no mechanism for bringing the plume material to ground exists.

The vertical growth of the ground-based nocturnal stable layer as measured by acoustic sounders has been found to be relatively shallow (<200 m). Therefore, with a combination of stack height and plume buoyancy, the effluents would be expected to level off in the neutral atmosphere that exists above the ground-based inversion. Any vigorous mixing at low levels at night would be purely mechanical and not sufficient to transport the elevated plume to ground.

Figure 12 shows the average depth of the nocturnal stable and convective layers at the Mavis Rd acoustic sounder site and the ground-level SO_2 concentration measured at WO7 for these cases. As shown, the depth of the stable layer before sunrise is about equal to the stack height. The stable layer is then gradually eroded from below with the onset of solar heating. A peak in the height of the mixed layer is reached at about 1100 EST. Thereafter, the height of the convective layer begins to decrease. The ground-level SO_2 concentration increases steadily from the early morning to about 1200 EST. The low morning concentration can be considered as residual or background pollutants from the previous day since the plume from the stack passes above the nocturnal stable layer. At sunrise, the incoming solar radiation enhances the convective mixing pushing the stable layer aloft above stack height. The SO_2 glc then increases rapidly through convective fumigation until the sun's zenith is reached.

The maximum SO_2 glc occurs in the mid-afternoon ($\sim$1400 EST) corresponding to the decrease of the convective layer and decreases sharply at the transition period when the nocturnal stable layer reappears ($\sim$1600 EST).

TABLE VI

CASES WHEN DAILY HOURLY MAXIMUM SO_2 GLC EXCEEDED 50 ppb - WO7 MONITOR

Date	Time (EST) 0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1900
July 23/81	1	6	5	5	14	6	37	14	6	20	2	10	58
July 27/81	1	2	3	3	21	25	5	14	42	58	36	21	9
July 31/81	2	6	10	5	4	6	21	50	72	80	14	14	12
Aug 19/81	20	20	30	40	65	15	35	405	370	280	190	130	20
Sept 1/81	10	20	20	20	20	25	45	30	59	15	8	3	5
Sept 16/81	0	1	6	24	17	20	56	13	46	42	6	5	5
Oct 12/81	0	2	4	19	42	3	39	75	21	0	0	0	1
Oct 13/81	1	3	6	18	22	15	12	10	59	77	29	5	2
Oct 30/81	4	4	8	20	31	42	89	51	41	27	6	8	5
Nov 4/81	5	6	7	7	8	9	11	19	32	33	53	67	23
Nov 10/81	3	4	9	32	23	25	21	26	19	14	10	11	63
Nov 12/81	7	5	7	8	10	16	59	77	92	50	26	22	22
Nov 26/81	4	9	7	5	4	137	9	8	7	7	5	7	7
Average (ppb)	4	7	9	16	22	26	34	61	67	54	30	23	18
# ≥50	0	0	0	0	1	1	3	5	5	5	2	2	2

To test whether the SO_2 plume would be reached by the convective layer resulting in fumigation, plume heights were calculated by a formula similar to that proposed by Briggs (1975) at the hour when SO_2 glc first exceeded 50 ppb for each of the cases tested in Table VI.

In summary, it can be seen in Table VII that 9 out of 13 cases show the potential of fumigation. Almost all cases compare well, especially when PIBAL data are input into the modified Briggs plume rise formula. For cases when PIBAL data are not available, the results were less favourable, perhaps due to incorrect estimates of stack height winds. More comprehensive descriptions of each of these 13 cases are included in Appendix C.

TABLE VII

COMPARISON OF PLUME RISE AND SURFACE CONVECTIVE HEIGHTS

Date of Exceedance	Modified Briggs (Research) Plume Rise Formula Input Values		Surface Convection and Plume Intersect
	Surface Data	PIBAL Data	
July 23/81	x		yes
July 27/81	x		yes
July 31/81	x		no
Aug 19/81	x		yes
Sept 1/81	x		marginally
Sept 16/81		x	yes
Oct 12/81		x	yes
Oct 13/81		x	yes
Oct 30/81*[1]	x		yes
Nov 4/81*[1]		x	yes
Nov 10/81*[1]	x		no
Nov 12/81*[1]	x		no
Nov 26/81		x	yes

*[1] An elevated stable layer is present

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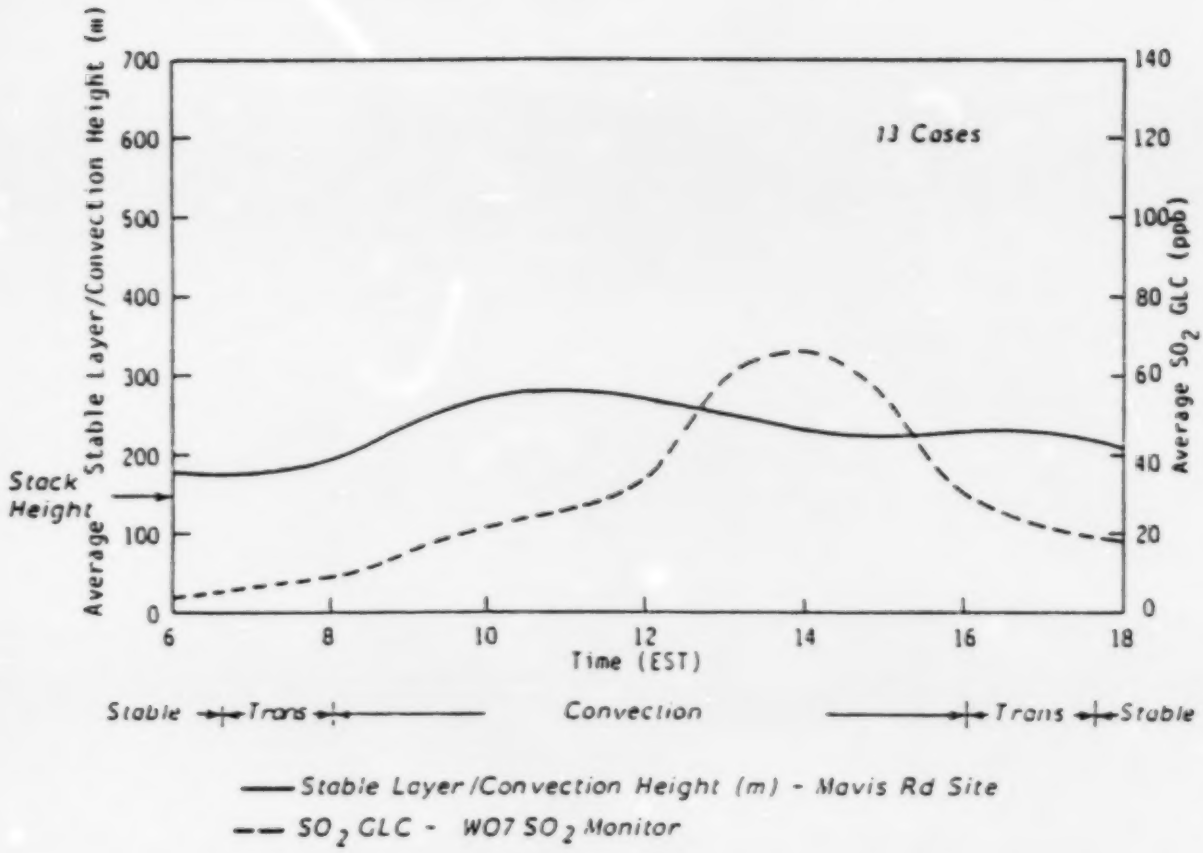

FIGURE 12

AVERAGED SO_2 GLC WHERE CASES EXCEEDED 50 ppb

7.0 CONCLUSIONS *

When operated in a simple monostatic mode, the acoustic sounder has shown good potential for providing continuous information on the thermal structure of the atmosphere from just about the surface to ~1000 m. Reliable observations within this range are of significant value in air pollution control.

The acoustic sounder data collected around Lakeview TGS have revealed the following results:

(1) Data capture was quite high. The few problems encountered were mostly associated with noise complaints by the owner of the property in which the bistatic sounder was located.

(2) The Evans Ave site showed the highest ambient noise level due to its proximity to the QEW highway. Even there, the sounder records were generally of good quality.

(3) In general, good qualitative agreement between acoustic soundings and measured temperature profiles was observed. The agreement between the minisonde and sounder was best for elevations of 100 to 600 m when there were strong, well-defined temperature inhomogeneities and little ambient noise.

(4) A variety of diurnal patterns were observed. In the predominant pattern, the sounder recorded a cycle of early morning surface-based stable layers, mid-day convection and evening surface-based stable layering.

In summary, the main advantages of acoustic sounders are (1) their ability to measure the depth of unstable and stable layers and (2) their capability of determining the exact time of inversion formation and break-up. One important application where this capability is very useful is, of course, in the operation of intermittent emission control programs.

The comparison between acoustic sounder and minisonde data presented in the present study was limited to only a small number of cases. It is therefore recommended that a more thorough intercomparison be carried out. A more efficient system of data chart analysis is also recommended. The present method of manual data logging, chart preparation and abstraction is extremely time-consuming. Techniques based on digitizing the high voltage sounder output look promising.

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* Work reported here describes technique acquisition that was substantially completed in 1982 at a time when greater emphasis was placed on dispersion from coal-fired stations than is now the case. The technique has since been successfully used at Pickering, (McMillan, Kerry and Lemyk, 1982), (Tam, 1984).

The digitized signal could be transferred to magnetic tape for computer processing. The experienced interpreter could review the digitized data, and if any questionable episodes are encountered, the episode could be manually interpreted.

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APPENDIX A

COMPARISON OF ACOUSTIC SOUNDER AND MINISONDE DATA

To verify the information from the facsimile records of the acoustic sounders, a comparison between sounder charts and minisonde flights was performed. The minisonde sounding system was the most appropriate available means of obtaining comparative data. The minisonde system has a greater height range than the acoustic sounder. Also, temperatures are recorded continuously with elevation so that smooth profiles can be obtained.

Figure A-1 displays the acoustic sounder records and minisonde profiles observed on September 11, 1981 at the Mavis Road site. There is generally good correlation of both the surface unstable and elevated inversion layers except for the 1315 EST case, when the sounder record shows a very unstable surface layer up to about 300 m in height and an inversion layer between the 300-m and 400-m levels. The minisonde profile indicates the presence of a superadiabatic layer extending from just above the surface to 200 m, followed by an inversion layer of about 200 m in depth.

The agreement between the acoustic sounder records and the minisonde profiles was very good on September 14, 1981 and October 13, 1981 as Figures A-2 and A-3 show. In general, good agreement extends from ground level to about 600 m, the layer we're most interested in. Signals are returned from layers higher than ~600 m if temperature inhomogeneities exist. However, returns from these higher levels become increasingly difficult to detect against background noise.

Figure A-4 displays the sounder records and minisonde profiles observed on October 14, 1981. Illustrated is the potential of the acoustic sounder to identify stable and unstable layers and to give some indication of the strength of the stability. For example, the 0900 EST minisonde flight shows a strong elevated inversion between 160 and 280 m. The acoustic sounder in turn produced a black shaded area at the same elevation. The 1230 EST minisonde flight and the acoustic sounder trace are in total agreement in both stability, strength and height (160 to 220 m) of the moderate stable layer, which is shown as gray to dark gray by the acoustic sounder.

Figure A-5 shows data collected on November 4, 1981. The 0745 EST minisonde flight shows a nearly isothermal layer above ~200 m which is characteristically shown by the acoustic sounder as a light gray trace.

In some cases the heights of elevated stable layers measured by acoustic sounder do not agree with those determined by minisonde. Two such examples are the 1100 EST flight on November 4, 1981 shown in Figure A-5 and the 1210 EST flight on November 5, 1981 shown in Figure A-6. A number of reasons can account for these differences as for example the location of the minisonde station, the non-vertical trajectory of the minisonde, etc.

COMPARISON OF PIBAL/MINISONDE DATA WITH ACOUSTIC SOUNDER RECORDS

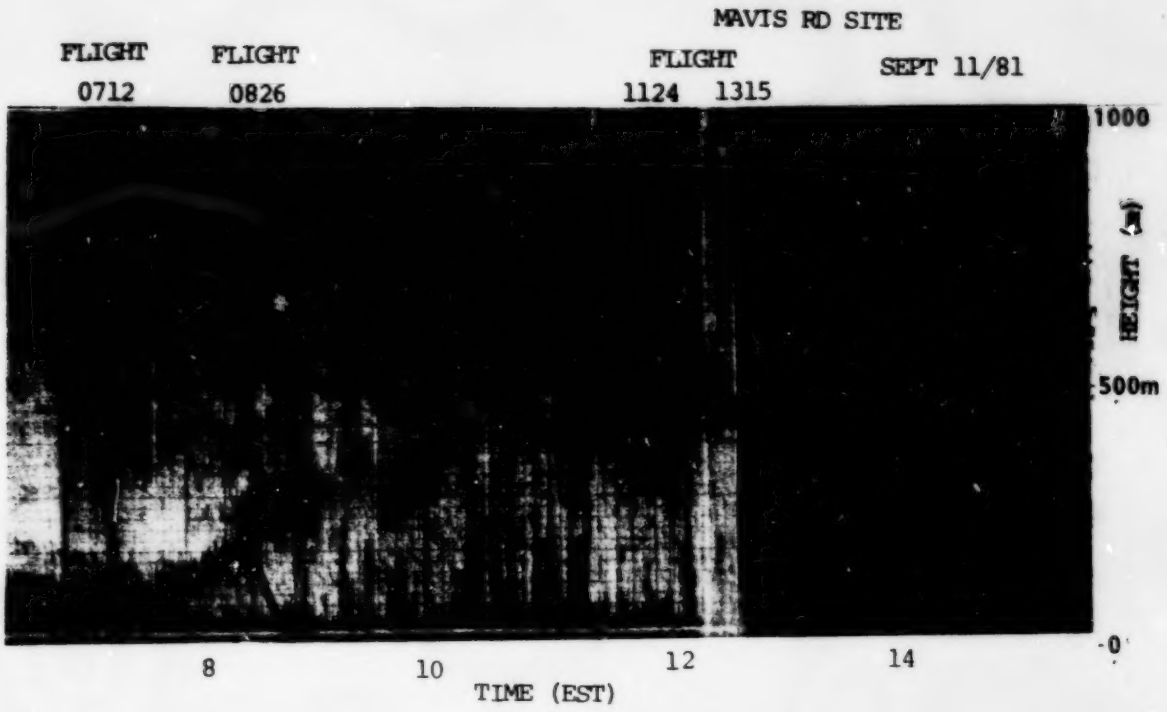


FIGURE A-1

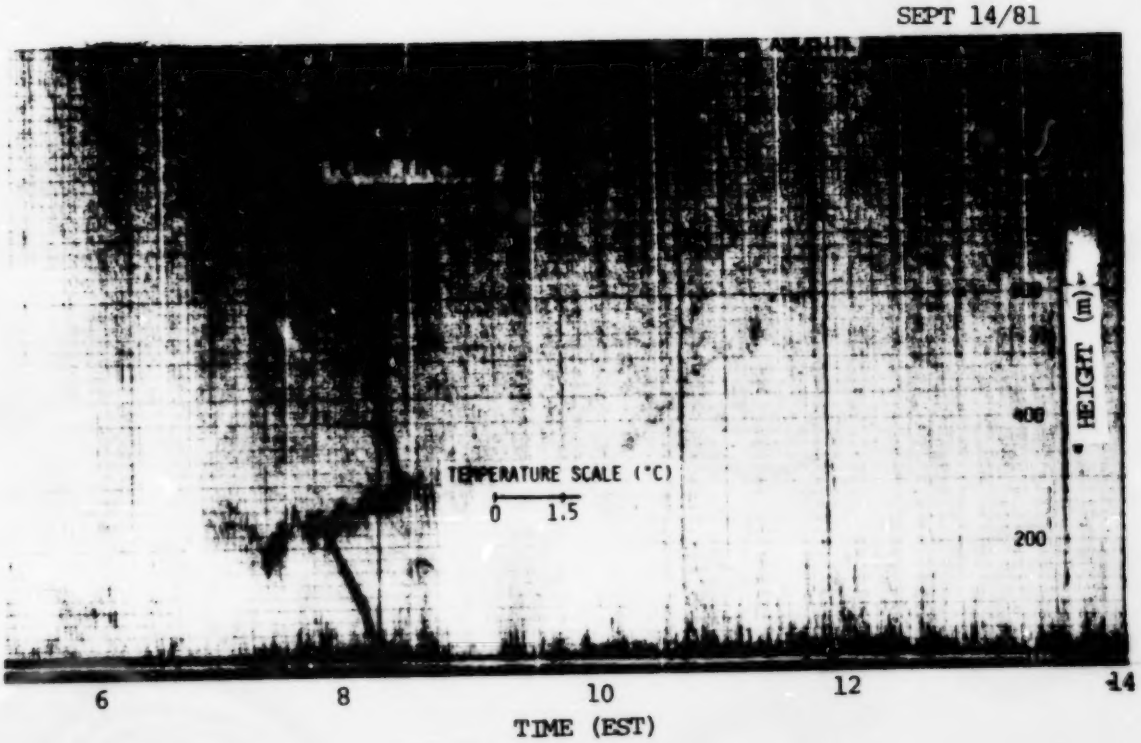


FIGURE A-2

84-167

COMPARISON OF PIBAL/MINISONDE DATA WITH ACOUSTIC SOUNDER RECORDS

MAVIS ROAD OCT 13/81

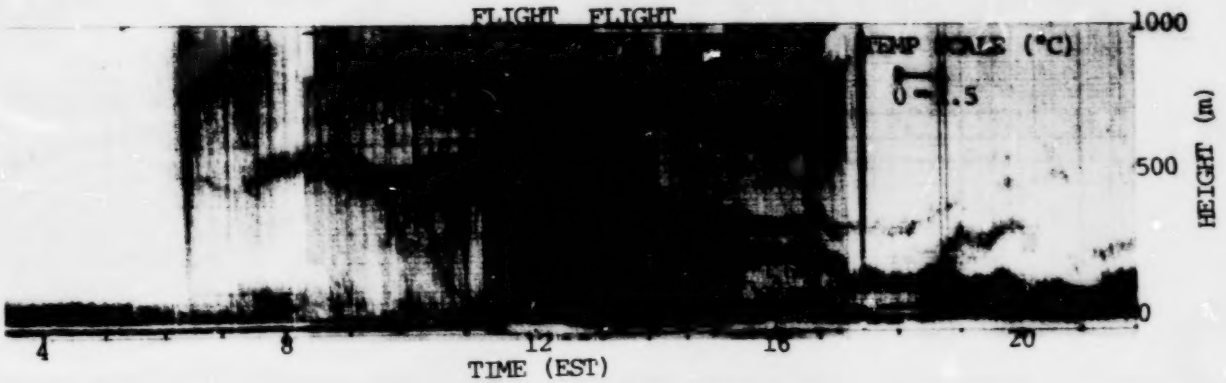


FIGURE A-3

MAVIS ROAD OCT 14/81

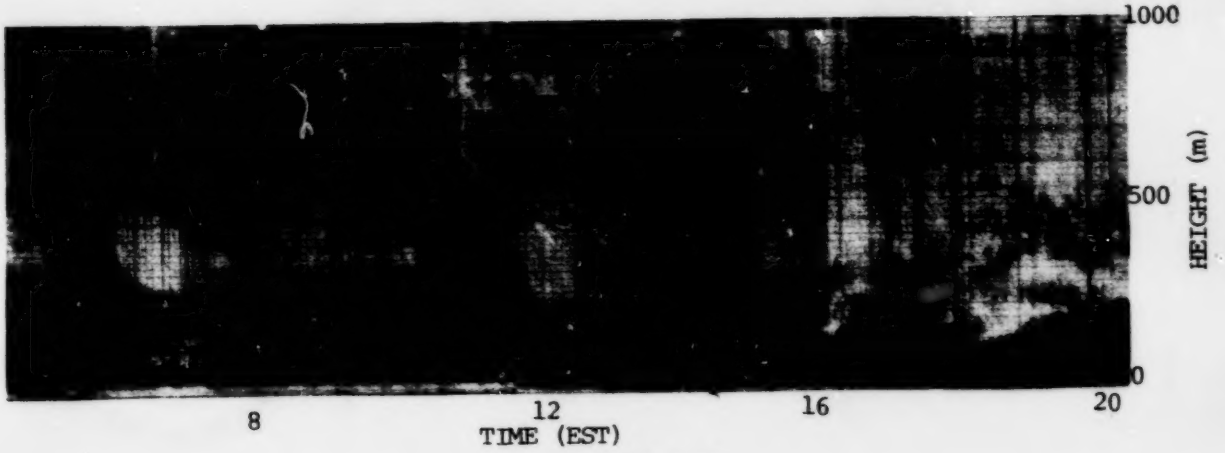


FIGURE A-4

EVANS AVE NOV 4/81

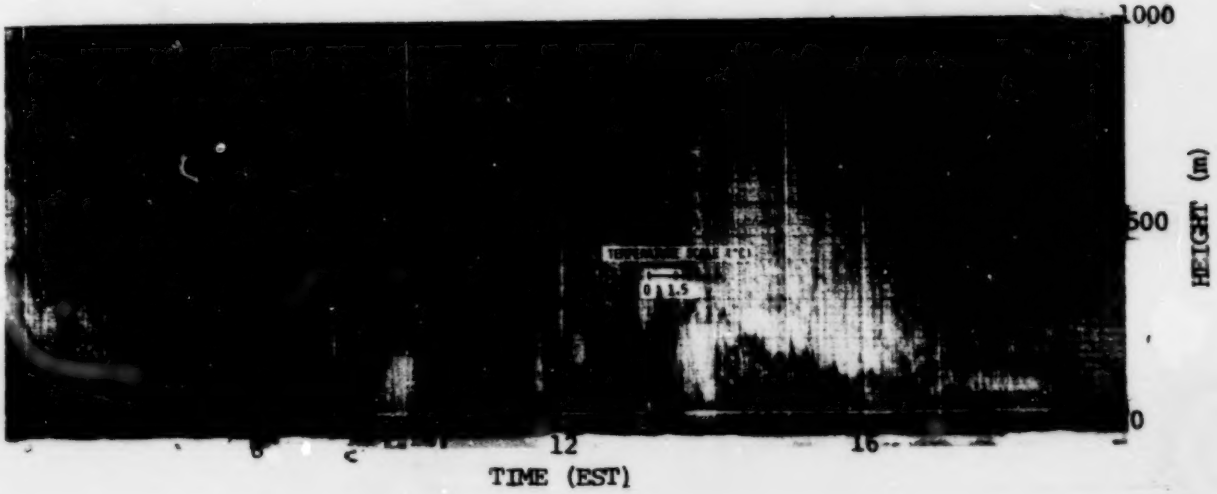


FIGURE A-5

84-167

COMPARISON OF PIBAL/MINISONDE DATA
WITH ACOUSTIC SOUNDER RECORDS

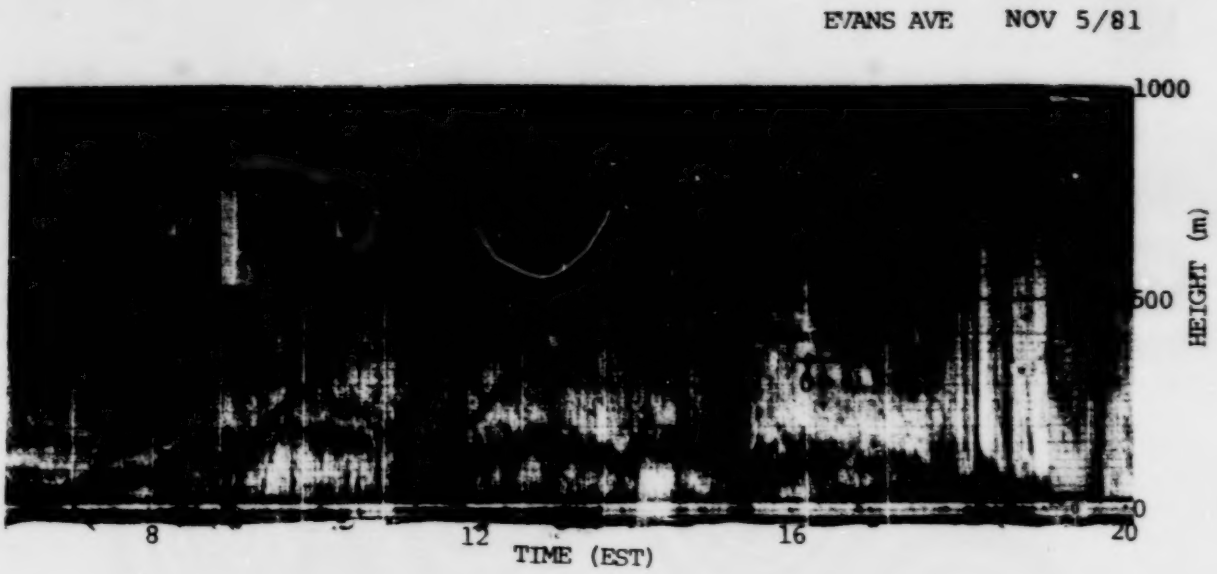


FIGURE A-6

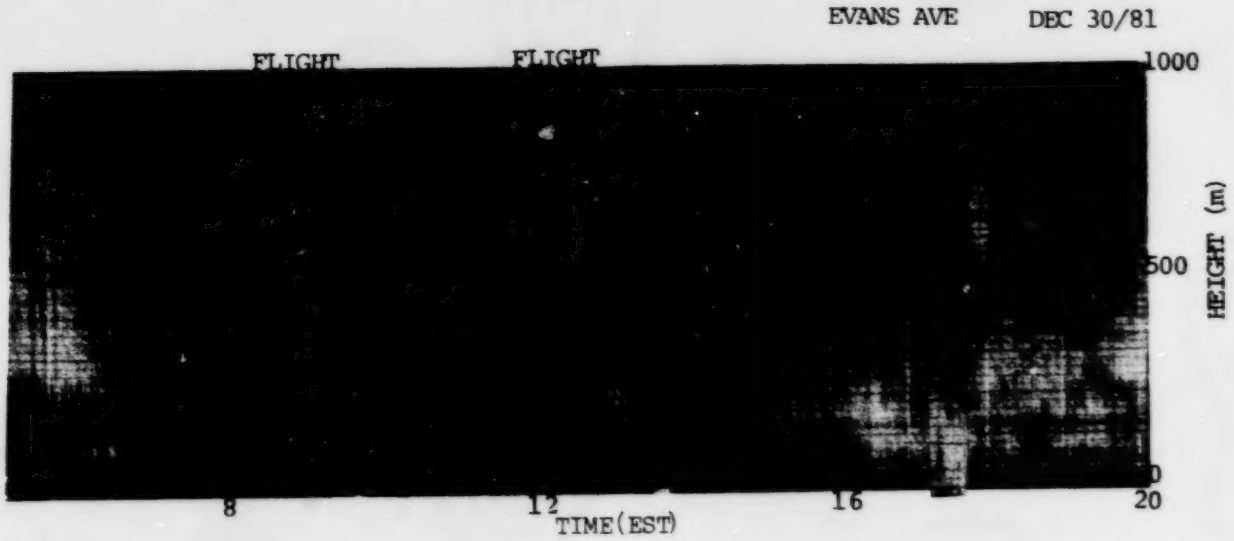


FIGURE A-7

The presence of an elevated stable layer directly above a strong convective layer makes acoustic sounder chart interpretation more difficult. The convective layer gradually erodes the stable layer from below. As a result, distinct separation of the two layers cannot always be made. The 1030 EST flight of December 30, 1981 shown in Figure A-7 is a good example of this.

A comparison of stabilities subjectively estimated from the gray scale of the acoustic sounder charts and from the minisonde temperature profiles has been shown in Table IV. As was pointed out earlier, there is good agreement between the heights and strengths of stable layers determined by the two techniques.

APPENDIX B

PRINCIPLES OF ACOUSTIC SOUNDER CHART INTERPRETATION

B-1 Echo Types

The feasibility of quantitative acoustic echo interpretation has been widely demonstrated (Brown and Hall, 1978; Daicopoulos, 1978). In the past, most studies have relied on facsimile recorders, where darkening of the chart record is directly related to the intensity of the scattered sound. The displayed patterns of atmospheric turbulence versus time can tell the experienced observer much about the status of the atmosphere; much more can be extracted when additional meteorological observations are made in conjunction with the acoustic sounder measurements.

It seems desirable to develop a classification scheme with descriptors that indicate the status of the atmosphere. The question of why characteristic facsimile patterns develop is sufficiently understood to allow classification.

The acoustic sounder produces two main types of echoes. Thermal echoes appear as vertical lines or spikes on the chart. White gaps between echoes, originating at ground level, are also usually seen on clear afternoons. The vertical temperature gradient is generally superadiabatic on these occasions and mixing is dominated by organized thermally-driven convective motion.

Echoes of the second type are mechanically induced shear or layer echoes. Shear echoes usually have a horizontal appearance marking the interface between layers of air. In this region the temperature gradient is subadiabatic and any atmospheric mixing that may be present is caused mainly by wind shear. Such conditions can be found aloft and cause large eddies to be suppressed in the vertical. The layer thus acts as a block to limiting the vertical transport of pollutants. These features can also be found at ground level at night when radiation cooling is present.

There are two possible causes for the absence of echoes: (1) there may be no turbulence (which can only be measured with the bistatic sounder), or (2) the temperature profile may be neutral.

There are four situations that lead to good echo returns:

(1) The existence of an interface where two layers of air of different characteristics meet.

(2) Radiative heating and cooling near the ground which produces strong vertical temperature gradients.

(3) The top of a mixed layer.

(4) Stable flow, with significant wind shear.

More detailed descriptions of the characteristics of echoes returned under each of these situations are described in the following section.

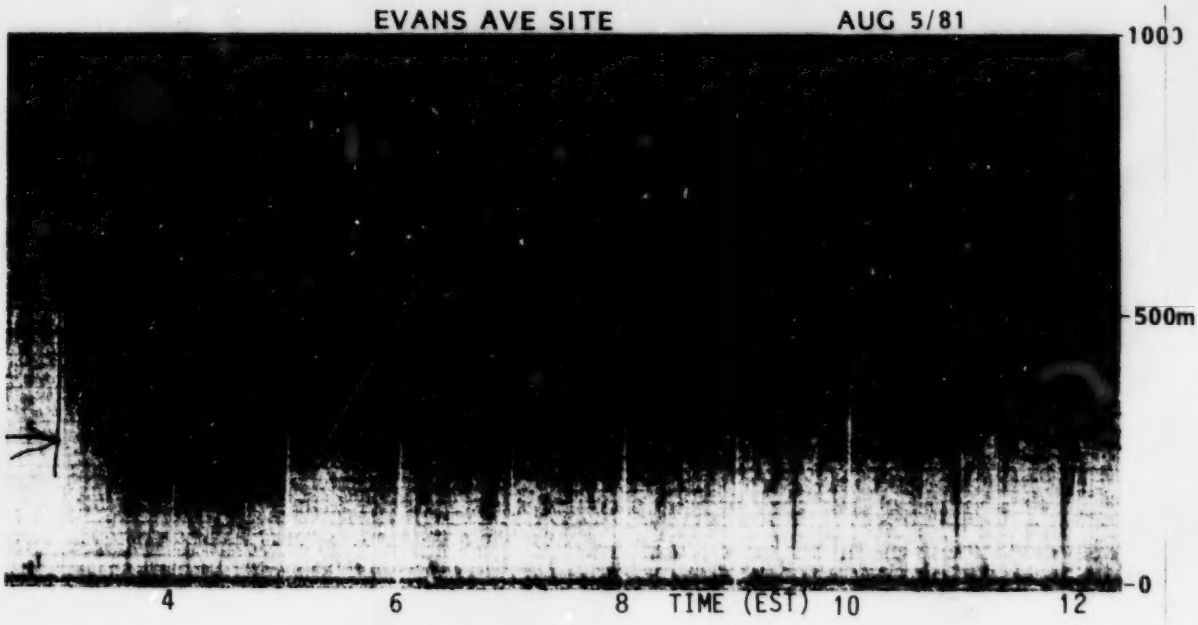
B-2 Pattern Classifications

Acoustic sounder records are classified according to pattern and divided into seven categories. (This is similar to the method used by AeroVironment.) Descriptions and probable causes of the seven categories follow:

(1) Random Noise - can be caused by rain, wind or traffic noise. Figure B-1 shows the dark pattern originating at the top of the record, representing rain in this case. Due to the high amplification of the echo return signal, extraneous noise is also amplified, obliterating return signals produced by thermal or mechanical fluctuations. The four horizontal bands are due to the chart drive tensioning system. Generally, good echo returns are obtained when wind speeds do not exceed ∿12 m/s.

FIGURE B-1

RANDOM NOISE



(2) Surface-Based Shear Inversions (SBSI) - caused by echoes ranging from homogeneous to complex. Horizontal and typically observed at night, these are associated with the development of surface temperature inversions.

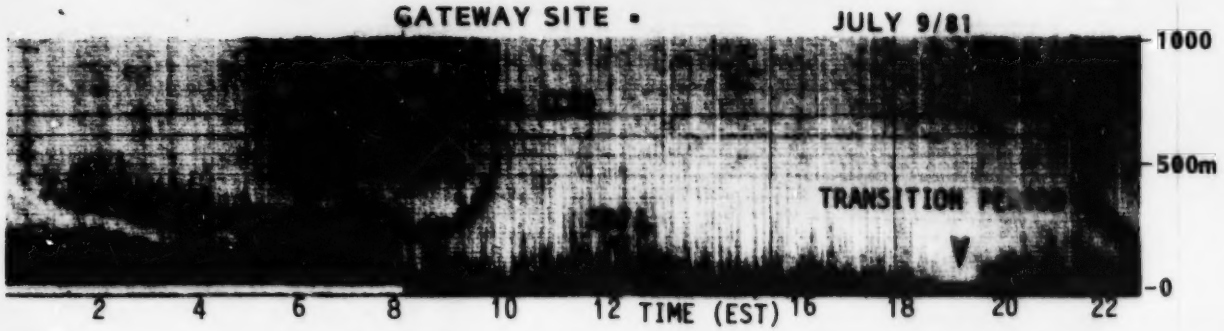
SBSI's are primarily due to wind shear. The greater the wind shear, the greater the depth of instability. A mechanism for establishing statically stable SBSI operates when cool air from a lake is advected over heated land. The echoes from such occurrences closely resemble those of weak density currents.

Following the lifting of the nocturnal inversion layer by convective plumes in the early morning, the lake breeze shows a typical SBSI appearing for usually several hours, or lasting all day occasionally, depending on the synoptic forces.

When winds exceed 15-20 m/s, even at 200 m above a strong SBSI, the turbulence generated may be strong enough to erode the continuous ground-based layer leaving only spikes of turbulent patches. Such echoes closely resemble buoyant convective eddies on the facsimile record (Figure B-2).

FIGURE B-2

SURFACE-BASED SHEAR INVERSION (SBSI)



(3) Double or Multiple Echoes - the separation between the layers of echoes can be either great (Figure B-3) or very small (Figure B-4).

FIGURE B-3

MULTIPLE ECHO PATTERN WITH
LARGE ECHO SEPARATION

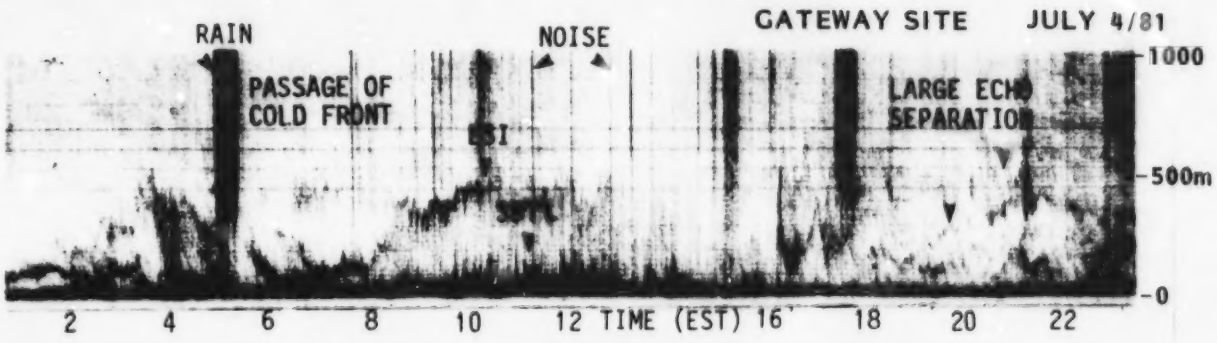
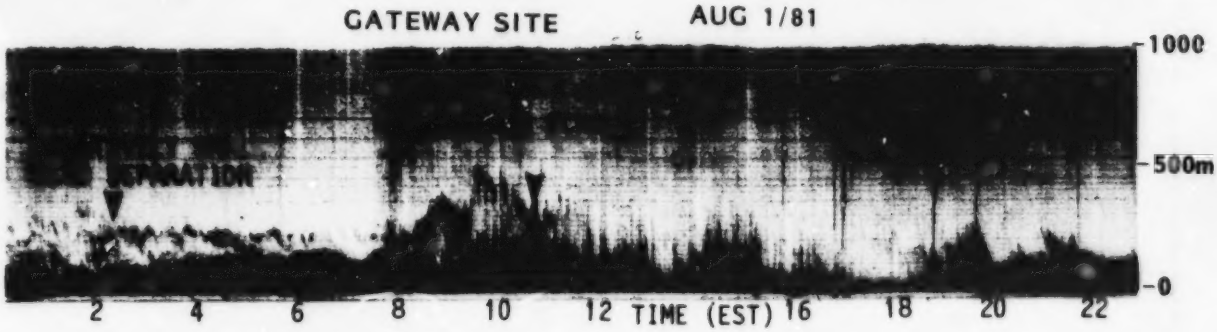


FIGURE B-4

MULTIPLE ECHO PATTERN WITH
SMALL ECHO SEPARATION



These patterns are usually associated with the passage of a cold front or with the evolution of the convective mixing layer after sunrise. They can also be related to the development of the surface-based inversion layer at night. When the wind speed drops to only a few m/s, the facsimile record of the nocturnal inversion usually returns, indicating little evidence of temperature structure between the layers.

Frequently, wave-like undulations are observed in multiple-layer returns. These undulations begin as complex structures such as Kelvin-Helmholtz instabilities.

(4) Surface-Based Thermal Layers (SBTL) - appear as vertical patterns. These echoes taper off with height and are normally associated with light winds and strong radiative heating of the ground; they also occur frequently in the late morning and afternoon. As in Figure B-5 the surface-based thermal layer typically begins at 0730 EST. Onset of the SBTL causes the nocturnal surface-based inversion to lift and eventually dissipate. In the late afternoon, a transition point is reached when the thermal effects of surface heating, due to the low solar angle, are at their minimum. Onset of the nocturnal inversion soon follows.

The appearance of the SBTL is caused by the slower daytime heating of air over water than over land. As a result, an air circulation system develops from water to land at low elevations, during the mid-morning hours of a clear summer day with light winds. The lake breeze then increases its land penetration, depth and speed, reaching a maximum by midafternoon.

The contributing factors to the existence of the SBTL are time of day, nature of surface, surface roughness and local cloud cover.

FIGURE B-5

SURFACE-BASED THERMAL LAYER (SBTL)

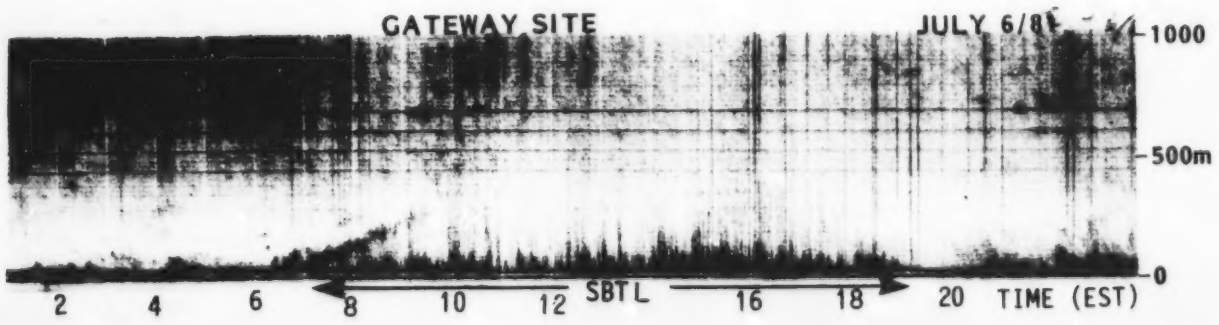
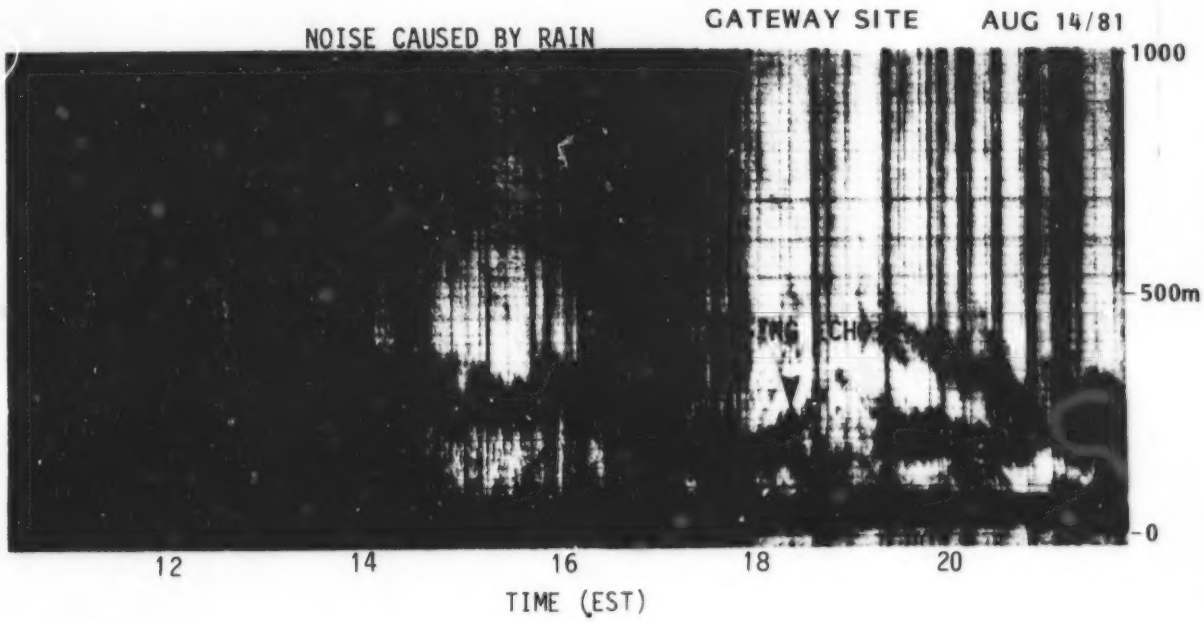


Figure B-5 shows a common morning situation in which the nocturnal layer is eliminated when a convective layer (SBTL) develops with the onset of solar heating. Typically the SBTL causes the nocturnal SBSI to lift and dissipate.

(5) Rising Echoes - are usually associated with the rise of shear echoes from the surface-based inversion layer. This occurrence can be associated with the passage of a cold front or with the initial formation of the convective mixing layer after sunrise. Figure B-6 shows a monostatic record which is associated with the passage of a cold front. Note the noise created by rain followed by the rising echo pattern as the front passed.

FIGURE B-6

RISING ECHO PATTERN



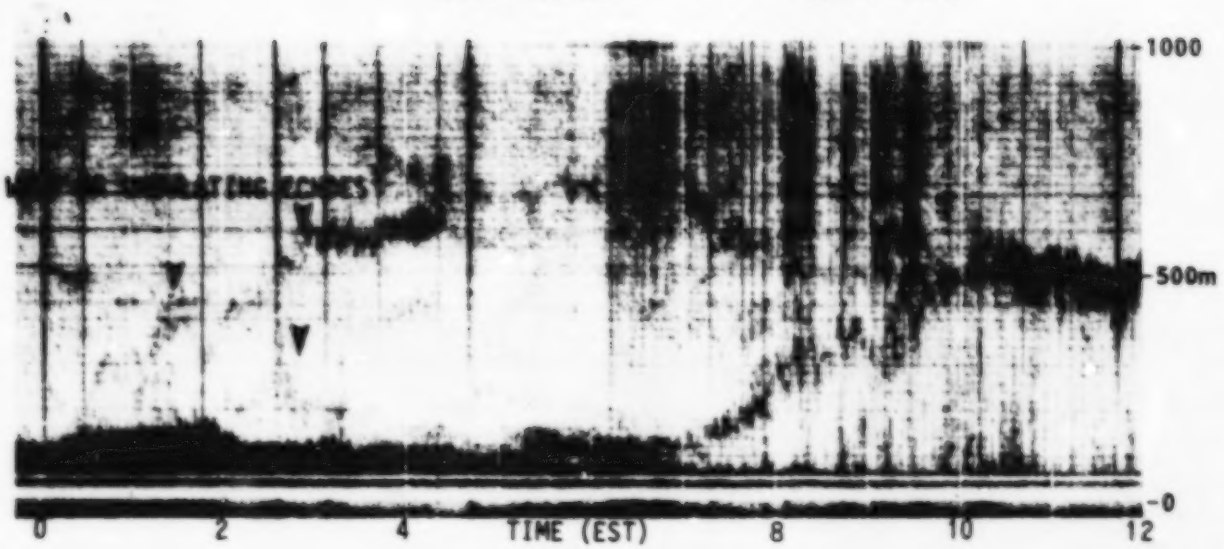
Rising echoes can also be related to the development of the nocturnal surface-based inversion.

(6) Descending Echoes - occur and gradually merge with surface echoes. Descending echoes can be associated with the passage of a warm front or with a subsidence inversion which merges with a surface-based inversion in the evening. Figure B-4 shows descending echoes merging with the surface-based thermal layer (SBTL).

(7) Wavy or Undulating Echoes - appear as wave-type multiple layer echoes (Figure B-7). Although these echoes seem similar to the multiple echo, the major difference between the two types is that wavy or undulating echoes are frequently associated with mechanical turbulence, resulting in stable lapse rates.

FIGURE B-7

WAVY OR UNDULATING ECHO PATTERN



It occasionally happens that echoes do not fall neatly into these major categories. In cases where they do not, referral to synoptic maps or local meteorological data will be necessary in order to interpret the results.

APPENDIX C

ACOUSTIC SOUNDER RECORDS OBSERVED DURING PERIODS OF HIGH GROUND-LEVEL SO_2 CONCENTRATIONS

The approach taken here will be to present a detailed case study, followed by a general review of the other 12 days when acoustic sounder records were available and the maximum hourly ground-level SO_2 concentration at W07 exceeded 50 ppb.

C-1 A Case Study - October 30, 1981

The nocturnal stable layer averaged about 100 m in height throughout the early nighttime (see Figures C-1(a) and (b)). Convective activity began at about 0745 EST and pushed the nocturnal stable layer aloft to ∿400 m by 1000 to 1100 EST. Convective mixing is strongest at these times as shown by the "spiky" sounder appearance of the charts.

It is noted that a sharp increase of ground-level SO_2 concentration followed soon after the decrease in convective activity and elevated stable layer height. The descending elevated stable layer reduces the height at which vertical diffusion was unobstructed. This in turn resulted in trapping of the SO_2 plume below the stable layer. Although the convective mixing height is reduced, the trapping of the SO_2 plume by the stable layer still allowed weak convection to fumigate SO_2 to ground.

Acoustic sounder records suggest that the diffusion rate of the plume is dependent on the height, thickness and strength of the elevated stable layer. The presence of this layer can act as a blocking layer which slows the vertical diffusion rate of pollutants.

Convective activity is strongest during clear sunny days when a large temperature differential exists between land and air. Strong convective activity alone can cause fumigation as the following cases show.

FIGURE C-1(a)

INVERSION CHARACTERISTICS WITH HIGH GROUND-LEVEL SO_2 CONCENTRATIONS

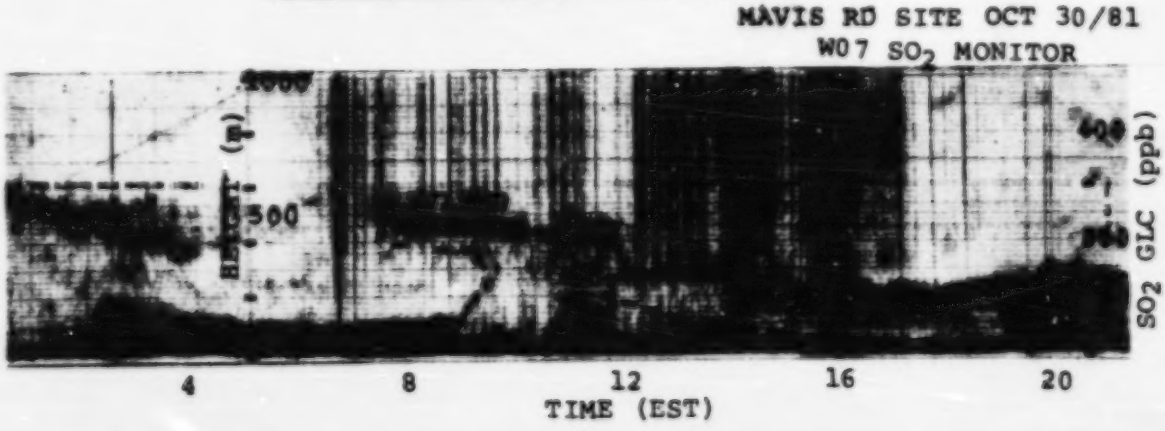
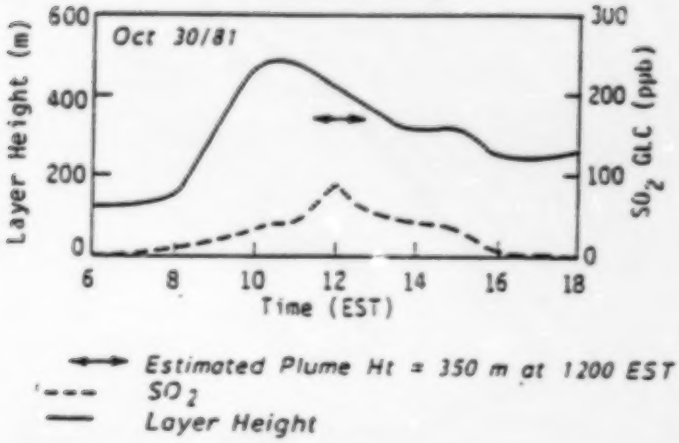


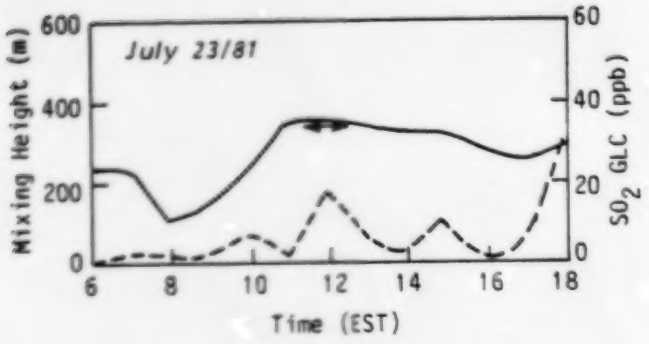
FIGURE C-1(b)



C-2 Documentation of the Relationship Between Mixing Height and Ground-Level SO_2 Concentrations

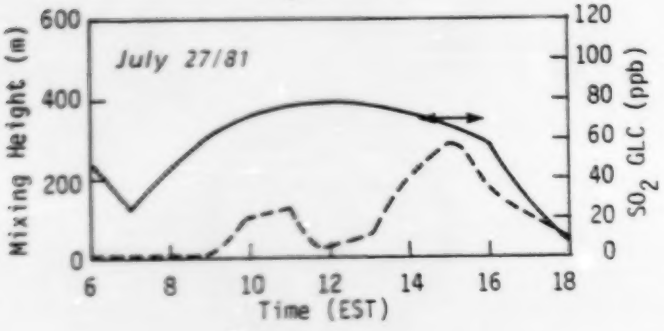
The cases shown in Figures C-2 to C-13 document the relationship between the calculated plume rise (Briggs, 1975), layer heights measured by acoustic sounder, and SO_2 ground-level concentrations.

Figure C-2



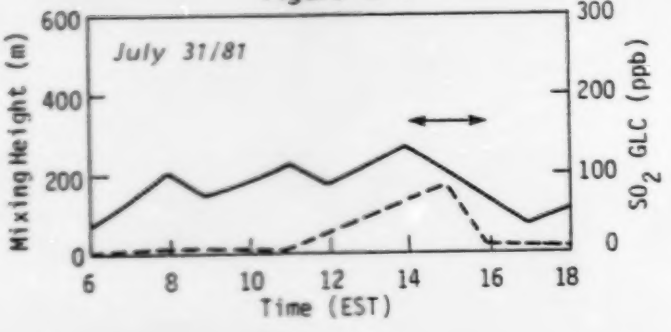
Estimated Plume Ht = 350 m at 1200 EST
SO_2
Mixing Height

Figure C-3



Estimated Plume Ht = 352 m at 1400 EST
SO_2
Mixing Height

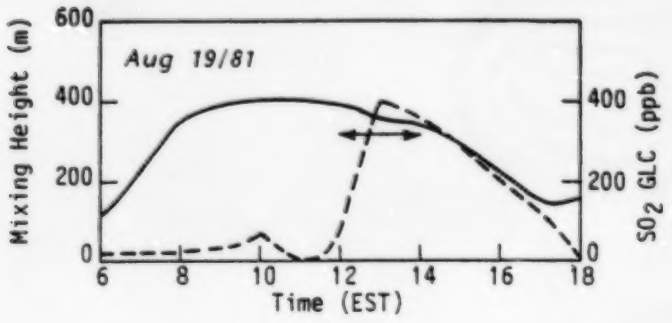
Figure C-4



Estimated Plume Ht = 324 m at 1500 EST
SO_2
Mixing Height

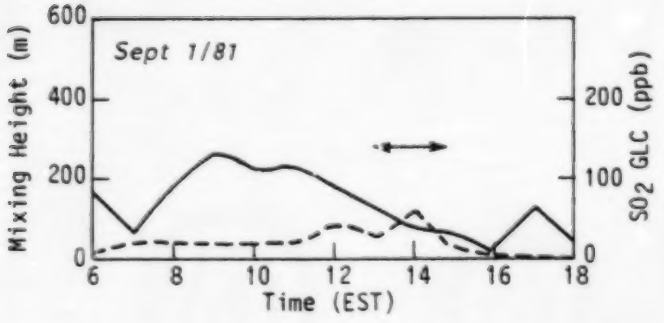
RELATIONSHIP OF MIXING HEIGHT WITH HIGH GROUND LEVEL SO_2

Figure C-5



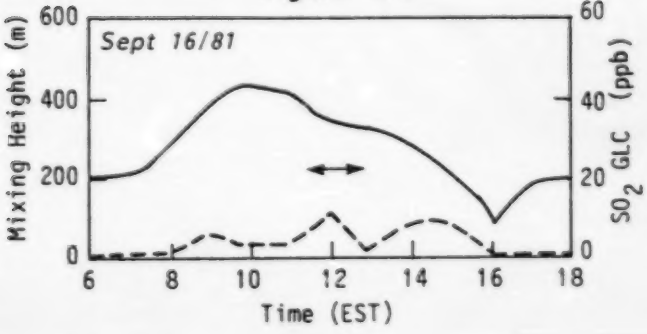
Estimated Plume Ht = 317 m at 1300 EST
SO_2
Mixing Height

Figure C-6



Estimated Plume Ht = 286 m at 1400 EST
SO_2
Mixing Height

Figure C-7

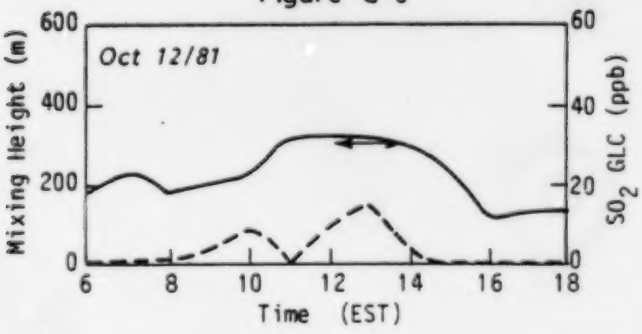


Estimated Plume Ht = 236 m at 1113 EST
SO_2
Mixing Height

RELATIONSHIP OF MIXING HEIGHT WITH HIGH GROUND LEVEL SO_2

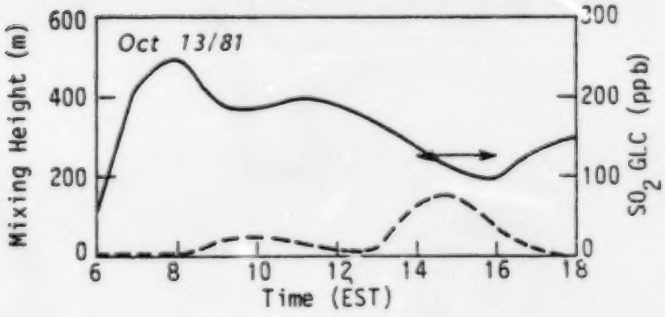
159498 RD

Figure C-8



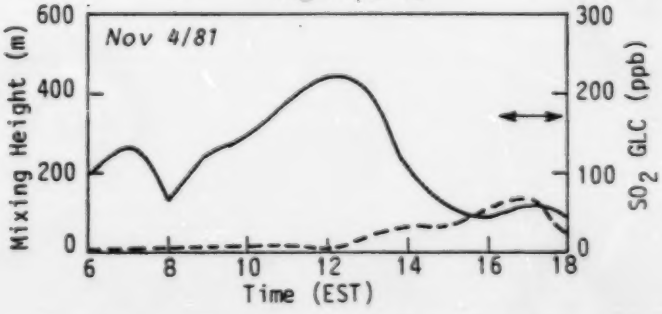
Estimated Plume Ht = 310 m at 1319 EST
SO_2
Mixing Height

Figure C-9



Estimated Plume Ht = 253 m at 1422 EST
SO_2
Mixing Height

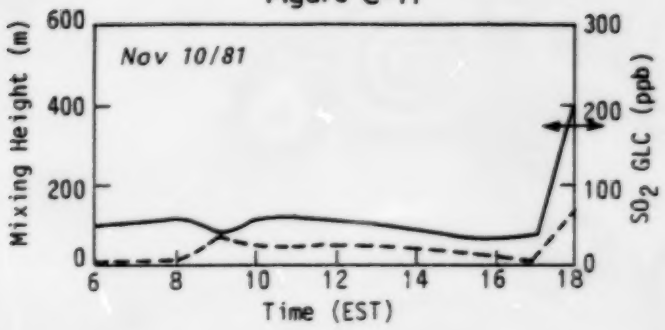
Figure C-10



Estimated Plume HT = 353 m at 1306 EST
SO_2
Mixing Height

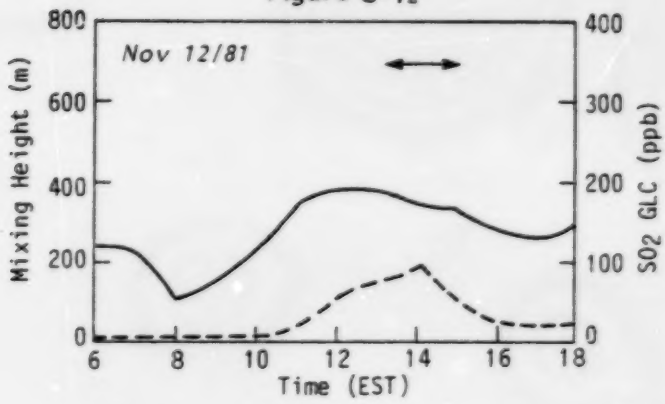
RELATIONSHIP OF MIXING HEIGHT WITH HIGH GROUND LEVEL SO_2

Figure C-11



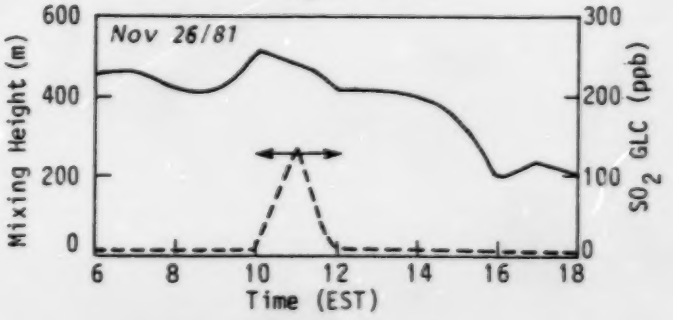
Estimated Plume Ht = 272 m at 1800 EST
SO_2
Mixing Height

Figure C-12



Estimated Plume Ht = 647 m at 1400 EST
SO_2
Mixing Height

Figure C-13



Estimated Plume HT = 259 m at 0916 EST
SO_2
Mixing Height

RELATIONSHIP OF MIXING HEIGHT WITH HIGH GROUND LEVEL SO_2